June 2023

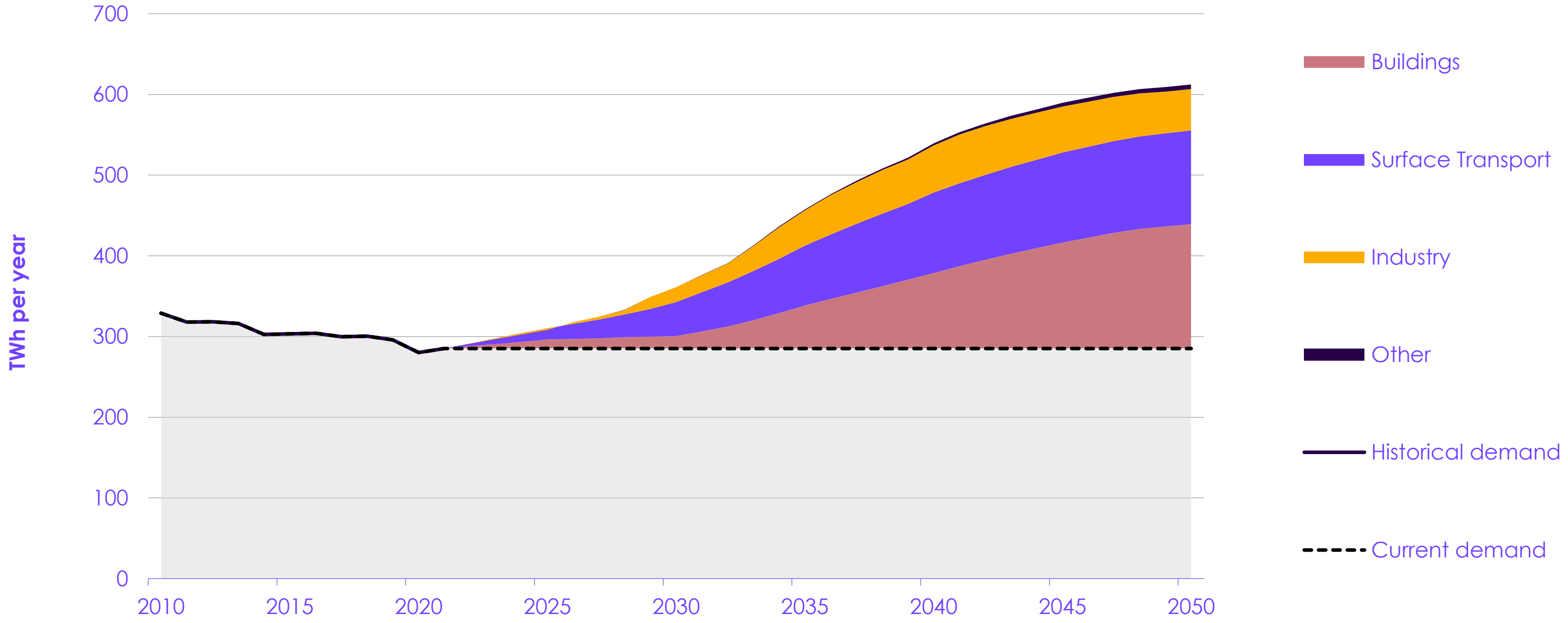
Delivering a reliable decarbonised power system

Rachel Hay (Climate Change Committee) and John Perkins (AFRY)

Setting the context

Electricity demand growth

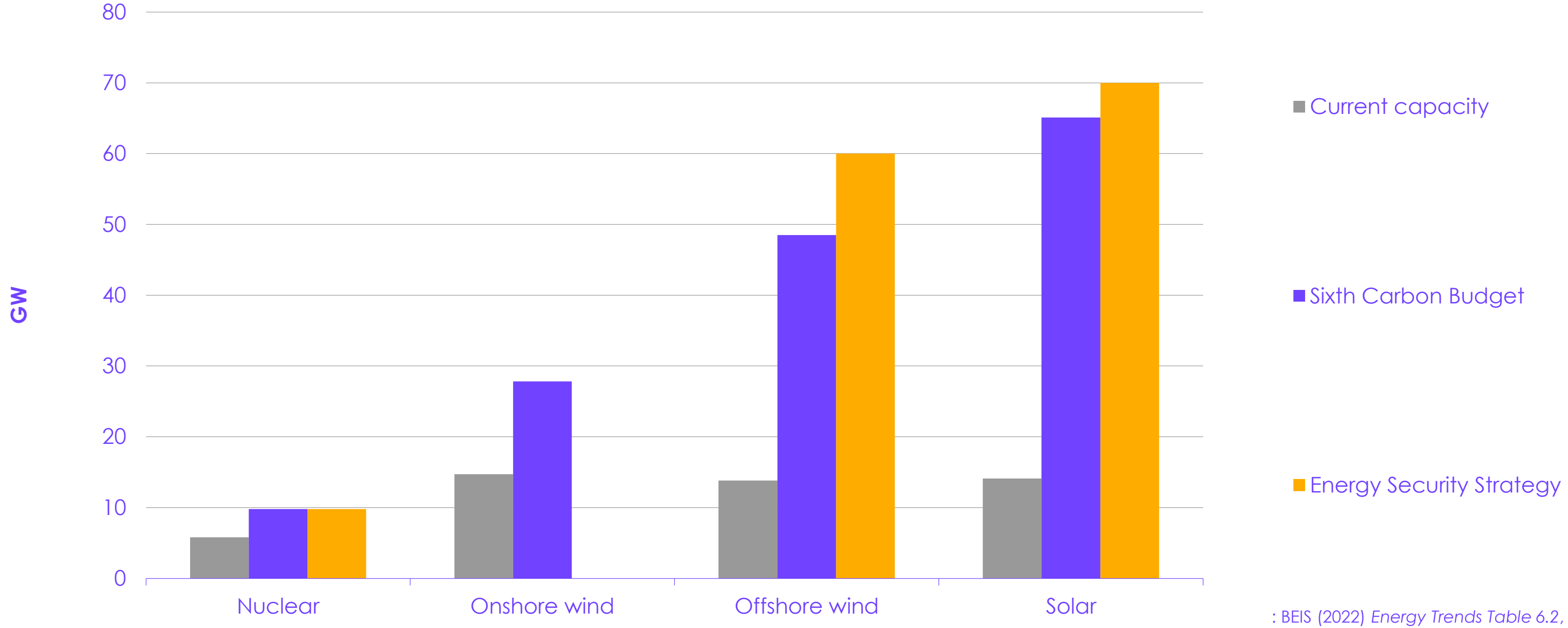
50% increase in electricity demand by 2035 and a doubling in electricity demand by 2050



Source
BEIS (2022) *Energy Trends*; CCC (2020) *The Sixth Carbon Budget*

Government's 2035 ambition in the Energy Security Strategy

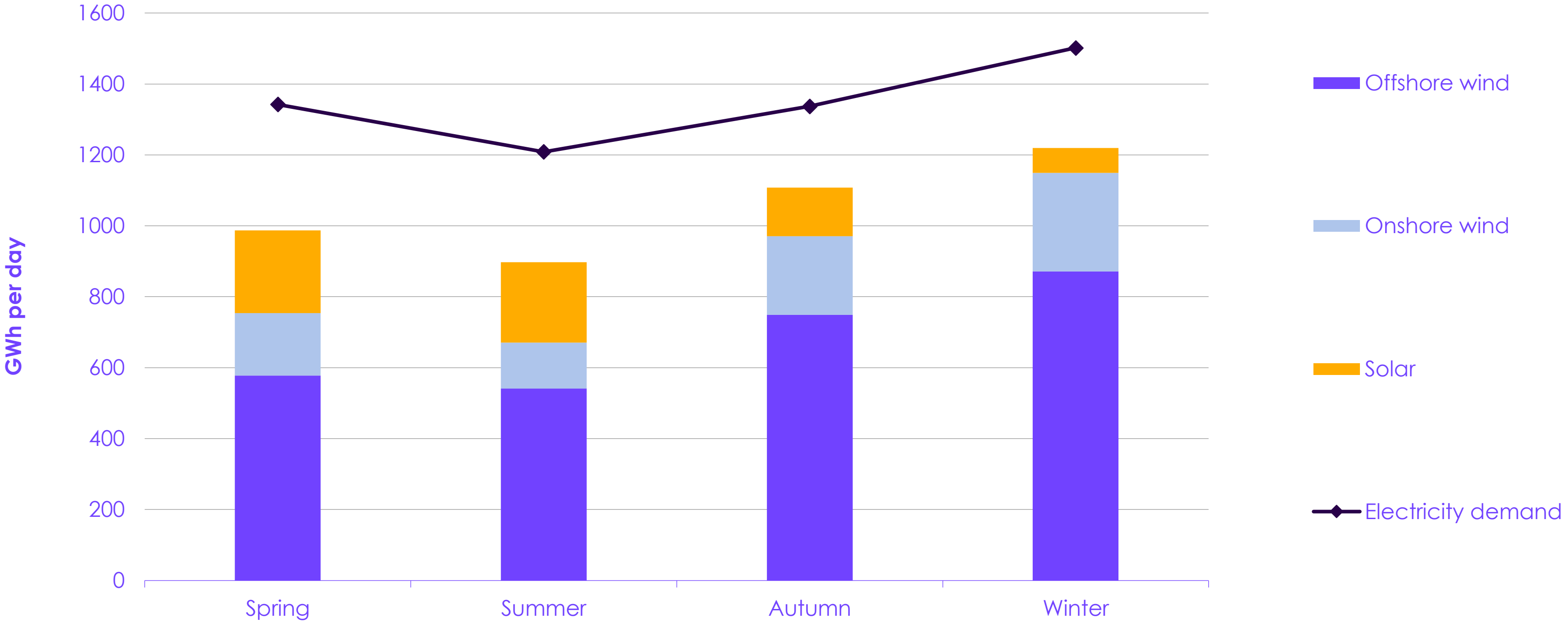
Build rates represent major increases on current capacity – well in excess of what has been achieved historically.



Source
: BEIS (2022) *Energy Trends Table 6.2*, BEIS (2022) *Digest of UK Energy Statistics Table 5.11*, BEIS (2022) *British Energy Security Strategy*, CCC (2020) *The Sixth Carbon Budget*, CCC analysis

Seasonal demand and renewable generation in 2035

Renewables supply the bulk of demand – with correlation between offshore wind and seasonal electricity demand



Source
CCC (2020) *The Sixth Carbon Budget*; AFRY (2023) *Net Zero Power and Hydrogen: Capacity Requirements for Flexibility*

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Delivering a reliable decarbonised power system
Our approach

New and detailed modelling of 2035's decarbonised power system, illustrating a realistic mix of solutions to achieve the Government's Energy Security Strategy, while operating a decarbonised GB electricity system based mainly on variable renewables.

- Co-optimised modelling of power and hydrogen production, storage and transport, using hourly modelling.
- 11 geographic zones across Great Britain and simultaneous modelling of pan-European interconnected markets.
- Uses historical weather data, including 2010's 'low-wind year' (a 1-in-50 year event) and an extreme 30-day period of wind drought.
- Consideration of wider enabling factors
- Assessment of climate-related risks to the energy system, given the increasing dependence on clean electricity, and how they can be addressed.

Key messages

Delivering a reliable decarbonised power system
Key findings

It is credible to deliver a reliable, resilient and secure decarbonised electricity system by 2035. Meeting our higher electricity demands; rapidly reducing our dependence on imported oil and gas; reducing our exposure to volatile international energy prices.

The Government has not provided a coherent strategy to achieve its goal.

Build rates, for generation and network capacity, must exceed what has been achieved historically in a number of areas – they represent large increases relative to today.

A number of processes – including planning, consenting and connections – are not fit for purpose. These must be urgently reformed to deploy infrastructure at sufficient speed.

Strategic direction is needed for hydrogen. Availability of low-carbon hydrogen remains a key risk.

Given the level of investment needed, we must not miss the opportunity to build in resilience from the start.

Key messages

While the policy framework has continued to develop over the past year, this is not happening at the required pace. Our assessment of the prospects of meeting the 2030 NDC and the Sixth Carbon Budget has worsened since last year.

Renewable electricity capacity increased in 2022, but not at the rate required to meet the Government's stretching targets, particularly for solar.

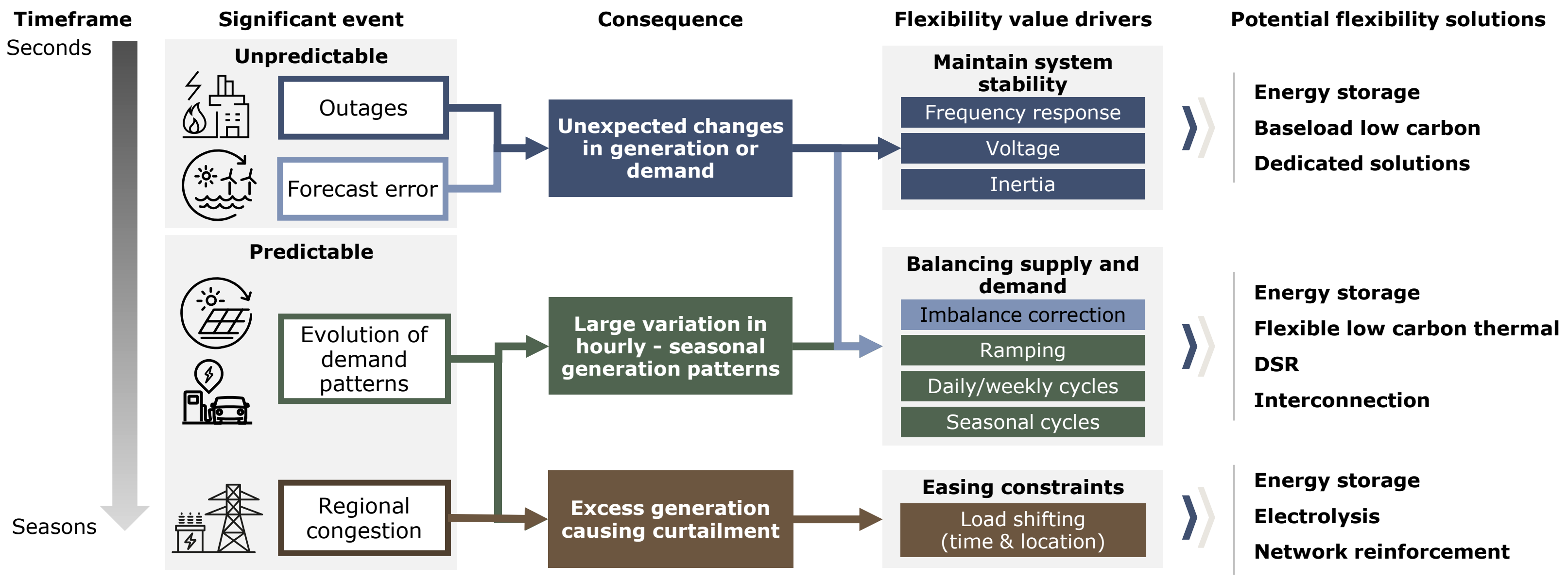
Planning policy needs radical reform to support Net Zero. There is a danger that the Net Zero transition is stymied or delayed by restrictive planning rules.

Expansion of fossil fuel production is not in line with Net Zero. The UK will continue to need some oil and gas until reaching Net Zero, but this doesn't in itself justify the development of new fields.

The Government needs to overcome the uncertainty being caused by its planned 2026 decision on the role of hydrogen in heating, to accelerate deployment of electric heating and press ahead with low-regret energy infrastructure decisions.

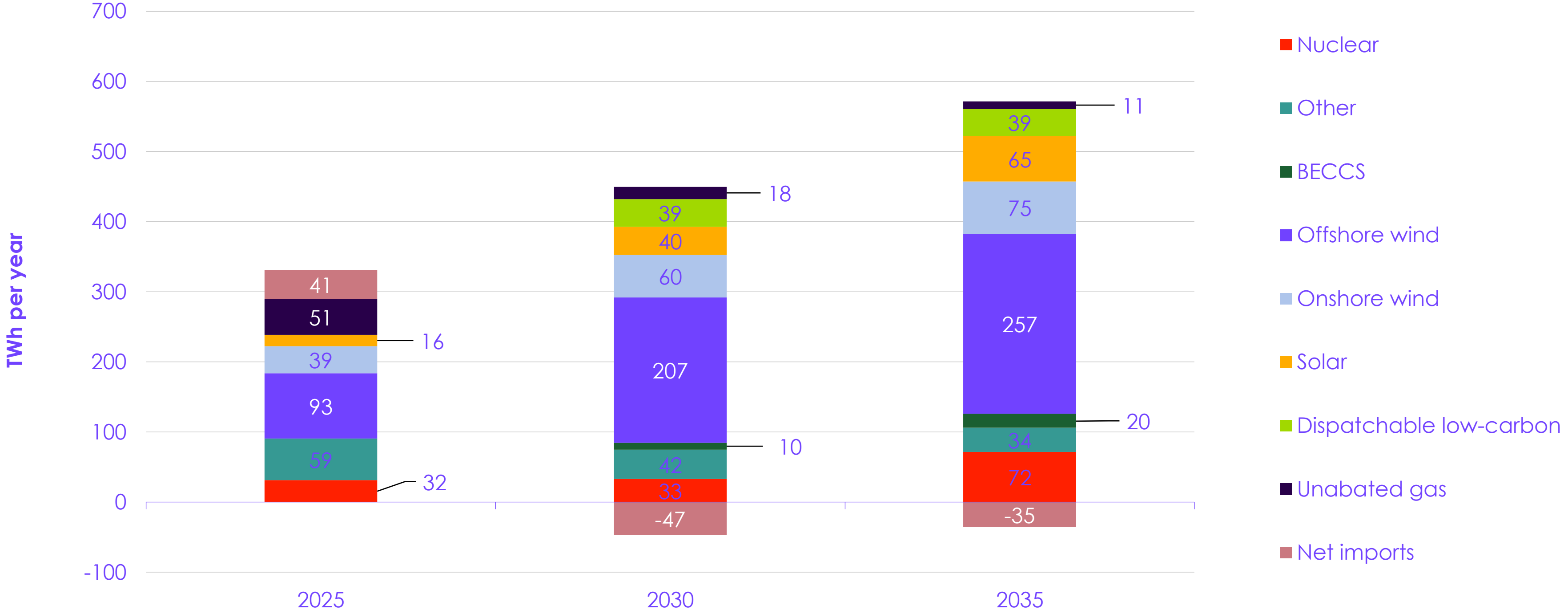
The 2035 power system

The capacity mix determined by the model reflects the types of flexibility that will be required to balancing an electrified and low carbon system



Changes in electricity generation

Low-cost variable renewables, especially offshore wind, the backbone of the future system, supplemented by complementary solutions



Source
AFRY (2023) *Net Zero Power and Hydrogen: Capacity Requirements for Flexibility*

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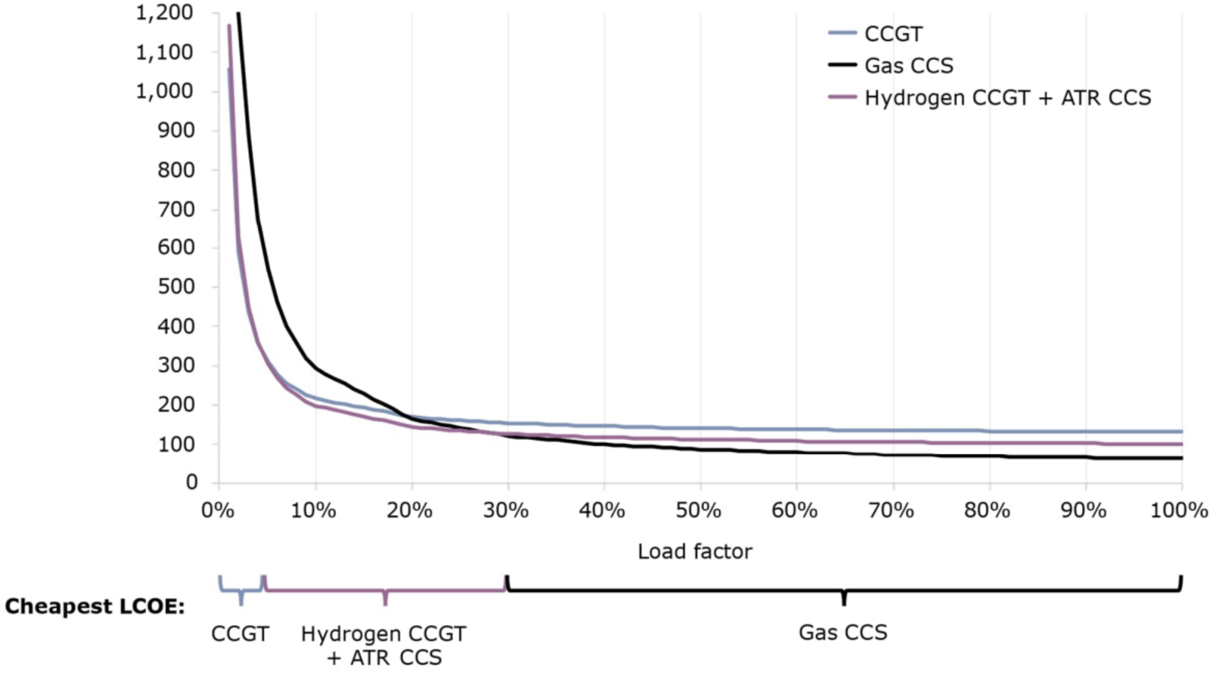
The duration of renewables variability is important in determining the lowest-cost system

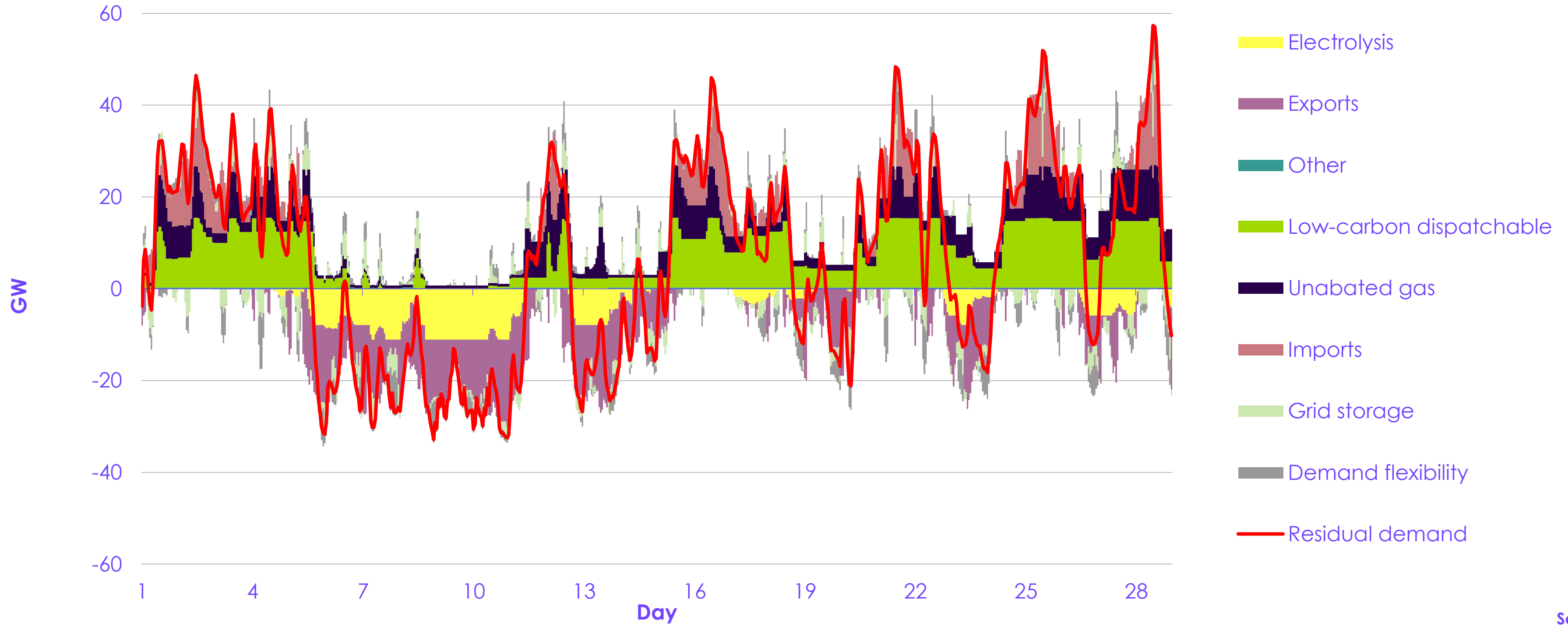
Load factors for dispatchable low-carbon power determine the mix between unabated gas, Gas CCS and hydrogen

Exhibit 4.9 – Levelised cost of electricity (£/MWh) of flexible generation technologies in 2035



Tools to complement variable renewables and nuclear

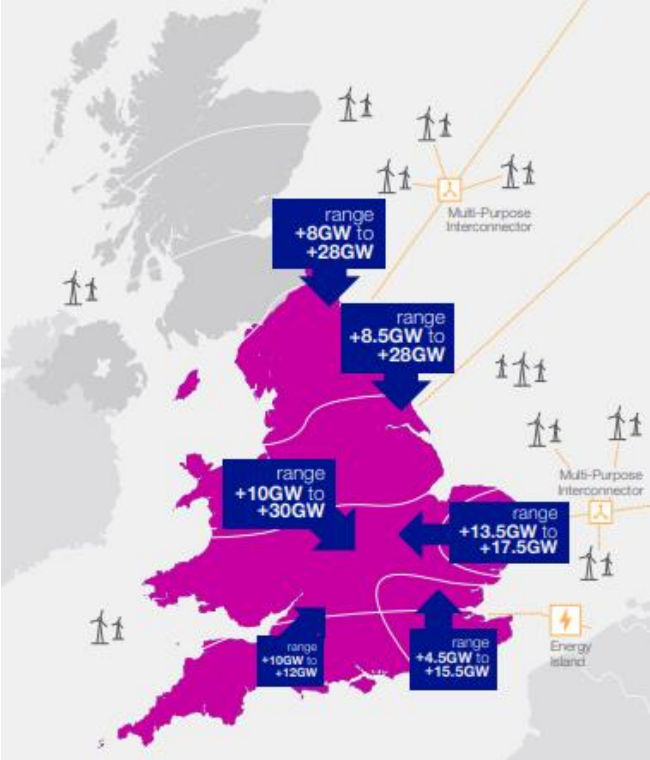
Portfolio of low-carbon flexibility solutions to bridge the gap in 2035 – four-week period of **highest** residual demand



Source
AFRY (2023) *Net Zero Power and Hydrogen: Capacity Requirements for Flexibility*

There is an urgent need for grid reinforcement to facilitate the decarbonised system

Around a doubling in transmission boundary capability is expected to be needed by 2035



- Modelling indicates need for a significant increase (e.g. around a doubling) in transmission boundary capability by 2035.
- Strategic investment will be key to timely and cost-effective delivery. The network should be designed and built anticipating major new sources of generation and demand to 2050.
- Given the scale of network build required, mitigation and adaptation needs must be considered holistically in strategic planning and investment.

Sources:
NGESO (2023) *Delivering for 2035: Upgrading the grid for a secure, clean and affordable energy future*
AFRY (2023) *Net Zero Power and Hydrogen: Capacity Requirements for Flexibility*

A range of scenarios and sensitivities were tested

We modelled 3 demand scenarios and 14 sensitivities in 3 broad groups

High scenario

Central scenario

Low scenario

Sensitivities

Technology mix

- Lower cost grid scale storage
- Low RES/Nuclear
- Low RES/Nuclear & High gas prices
- Vehicle-to-Grid
- Biomass for Hydrogen

Technology risk

- No New Nuclear
- Delayed Salt Cavern
- Peaky Demand
- Faster unabated gas phase out

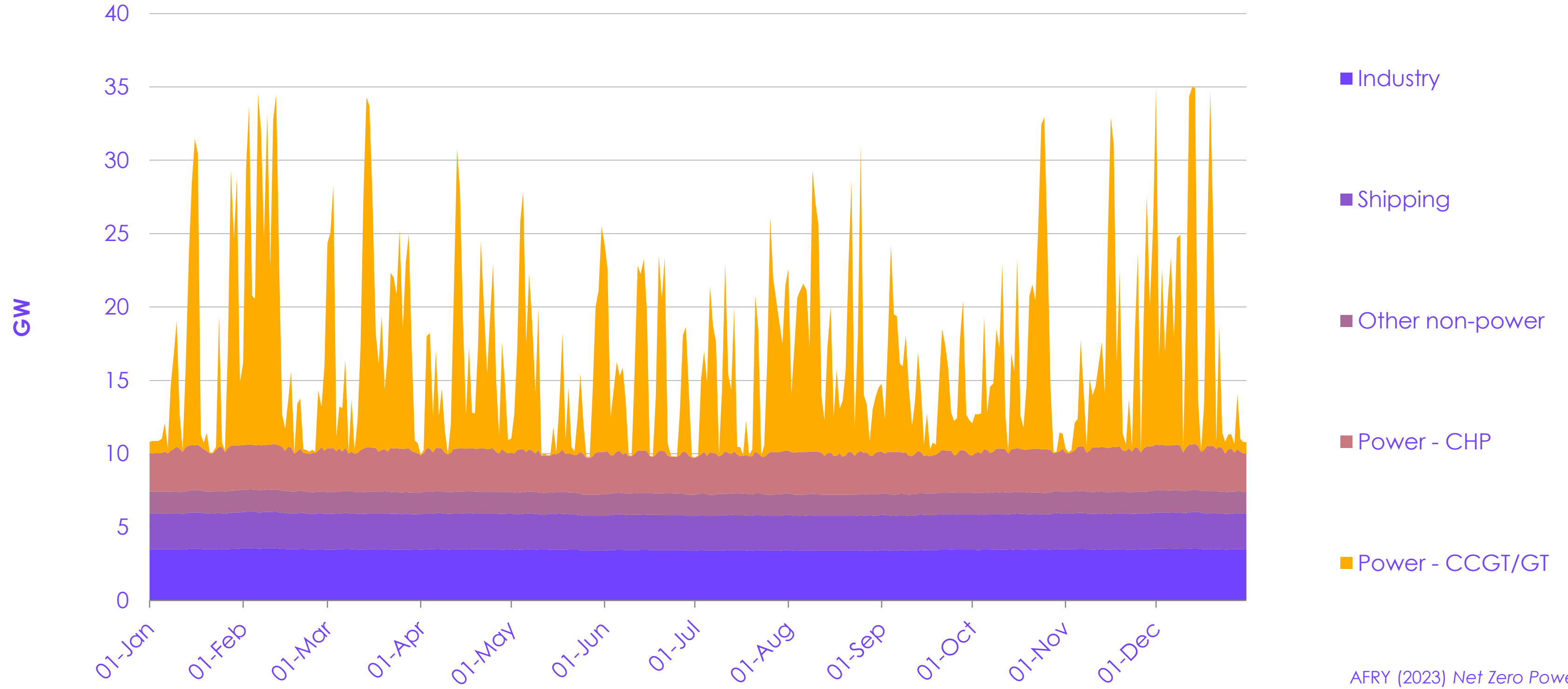
System stress events

- High Gas
- Low Wind Year
- Long Wind Drought
- Decentralised Balancing

Implications for hydrogen

Hydrogen's essential role in 2035

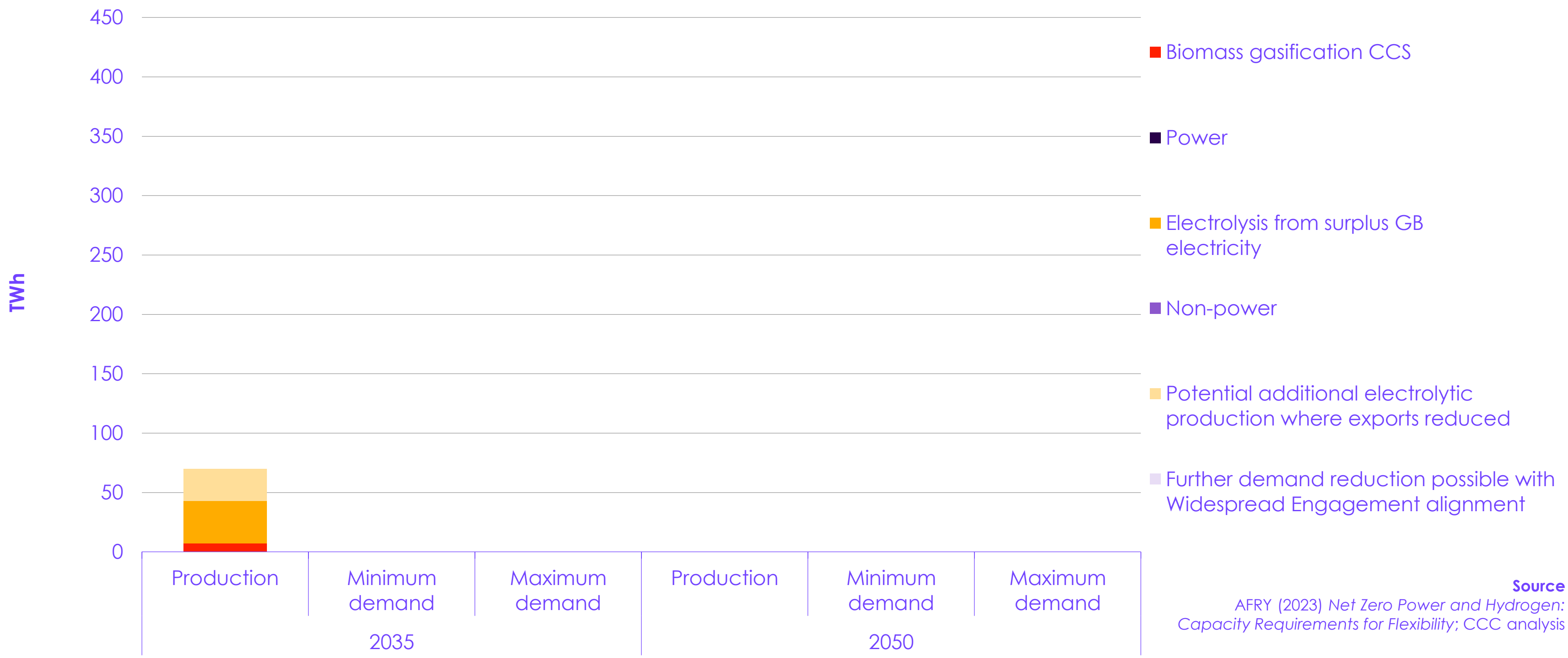
Hydrogen provides 'on-demand' power to meet peaks and back-up renewables – requiring significant hydrogen storage



Source
AFRY (2023) *Net Zero Power and Hydrogen: Capacity Requirements for Flexibility.*

Will we have enough domestic green hydrogen?

Unlikely that all hydrogen demand in 2035 can be met from domestic non-fossil fuel production based on the use of surplus renewables



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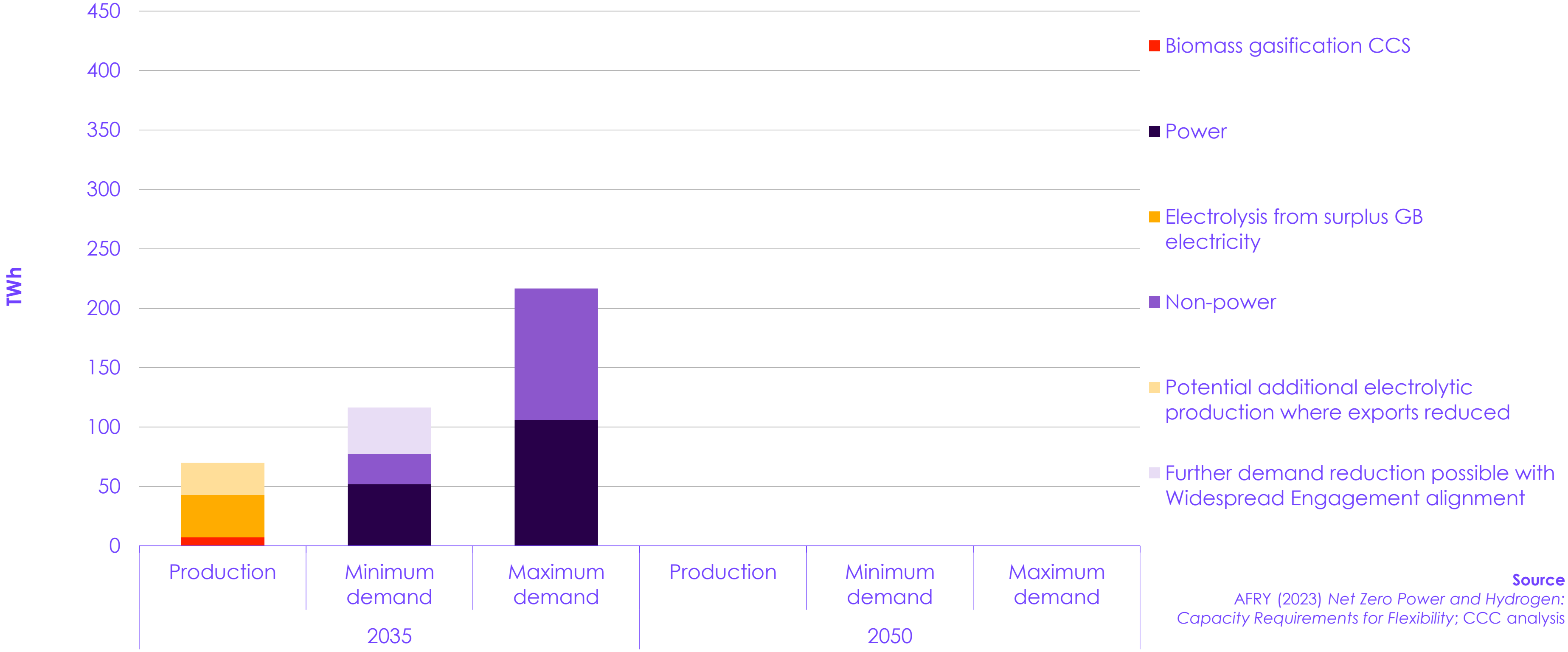

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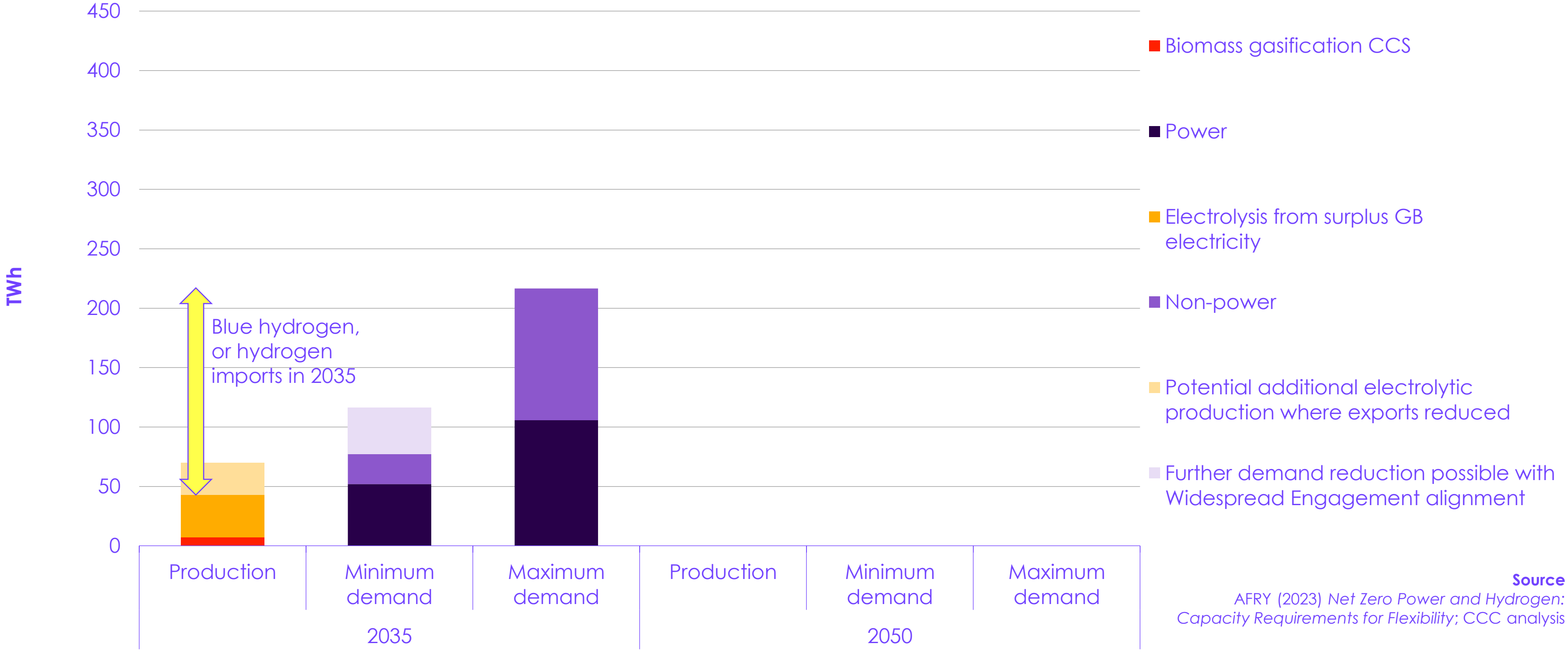

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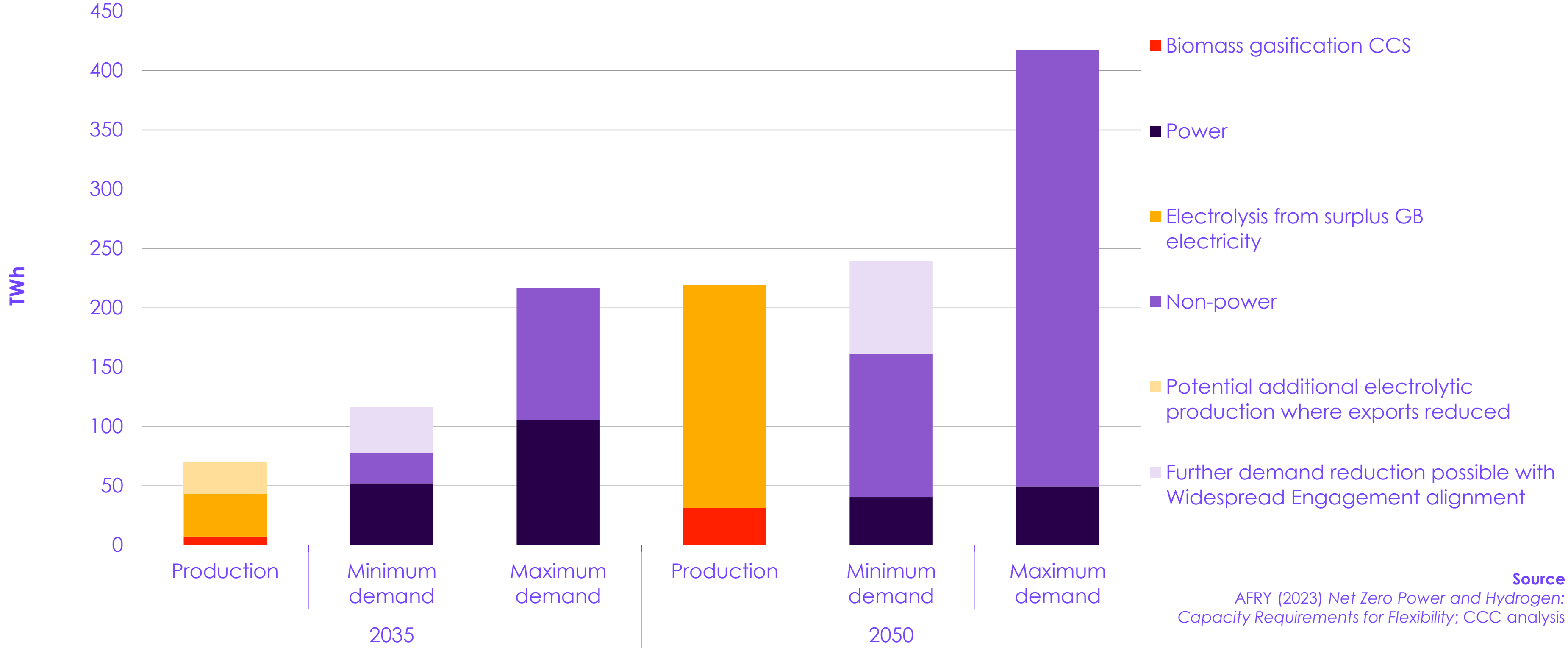
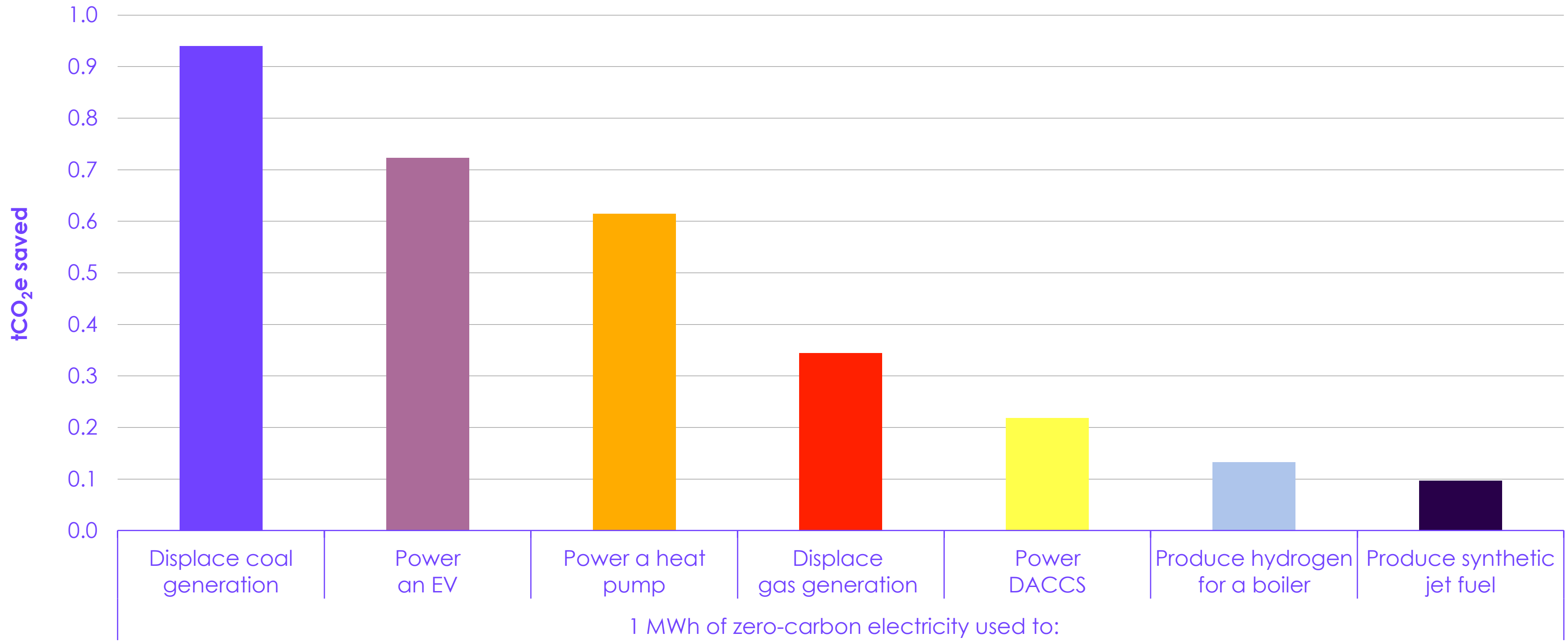


Source
AFRY (2023) *Net Zero Power and Hydrogen: Capacity Requirements for Flexibility*; CCC analysis

Best uses of zero-carbon electricity

Zero-carbon electricity must be used optimally

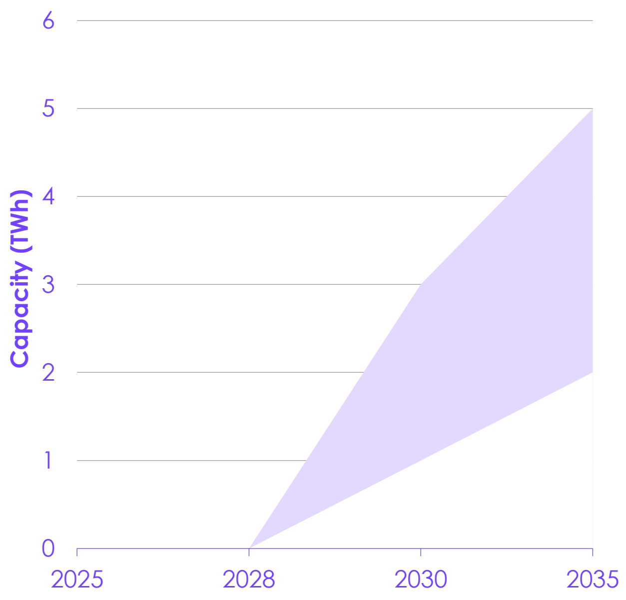


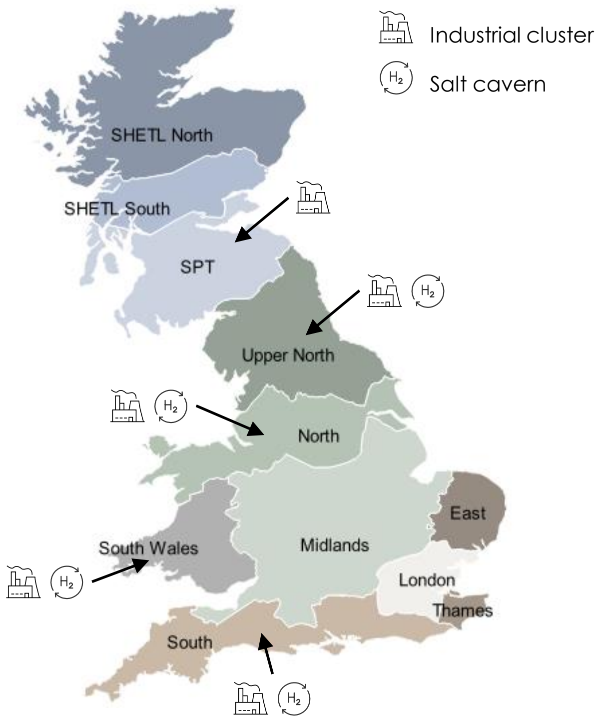
Source
CCC analysis

Substantial infrastructure build will be needed

It is not sensible to delay all decisions on hydrogen infrastructure until 2026

Hydrogen storage capacity in operation





GB hydrogen pipeline capacity in 2035 (GW)

	2028	2030	2035
East - Midlands	0.0	0.6	0.7
London - Midlands	0.0	3.1	3.7
London - South	0.0	2.5	3.0
London - Thames	0.0	0.2	0.4
Midlands - North	0.0	6.0	7.3
Midlands - South	0.0	0.0	0.0
Midlands - South Wales	0.0	0.2	0.5
North - Upper North	0.0	1.0	3.0
SHETL North - SHETL South	0.0	0.4	1.3
SHETL South - SPT	0.0	1.7	2.6
Upper North - SPT	0.0	1.3	2.8
Total	**0.0**	**16.9**	**25.1**

Building in climate resilience

The system must be made resilient to extreme events

Consideration of changing climate hazards is essential for effective planning of the future energy system

- **Climate risks to the power system are among some of the most urgent risks facing the UK** in the latest UK Climate Change Risk Assessment (CCRA3). One of 8 top priority risk areas, due to the urgent need to integrate adaptation into key decarbonisation policy decisions.

- Current climate and weather-related interruptions to the electricity system are typically localised but poorly reported. However, recent events **highlight the potential scale of impacts from weather-related outages**. The vulnerability of interconnected systems is not well understood and may be significantly underestimated.

- **Changes in climate hazards will affect future energy supply and demand**.

    - Some of these will become more common and intense, and will have potentially larger effects on the system than today, including flooding, heatwaves and droughts.

    - Some hazards will become less likely but will still occur from time-to-time in the future, such as snow and ice.

    - Changes in some potentially important weather hazards remain uncertain – wind strength, wind regimes, storms and lightning.

In a range of areas, the risk of these events is increasing

The UK's climate will continue to change to 2050 and beyond, bringing risks of increases in weather types that could disrupt the future energy system

Table 1: Potential impacts on energy system due to climate trends & extreme weather events

Climate hazard	Expected change by mid-century	2°C global warming by end century	Potential impacts on energy system
Heatwaves	~50% chance of 2018 summer each year*	~50% chance of 2018 summer each year	Efficiency loss at thermal generation plants Higher demand for electricity for cooling meaning more generation required Maximum operating temperatures for components exceeded Efficiency loss on transmission lines at high temperatures Restrictions of thermal ratings of assets
Flooding (river, surface & coastal)	~5% wetter winters on average ~10% increased intensity of heavy rainfall 10 – 30 cm increase in average sea levels**	~5% wetter winters on average ~ 20% increased intensity of heavy rainfall 25 – 45 cm increase in average sea levels**	Loss of generation capacity due to inundation Loss of transmission & distribution capacity due to flood damage, slips, ground movement/subsidence

* around 10-25% today; ** compared to 1981-2000 ***above 1981-2000 levels

Source: UKCP18 projections, CCRA3, IEA

In some areas, the risks are uncertain

Nevertheless the magnitude of potential impacts is large and must be planned for

Table 1: Potential impacts on energy system due to climate trends & extreme weather events

Climate hazard	Expected change by mid-century	2°C global warming by end century	Potential impacts on energy system
Drought	~10% drier***	~15% drier***	Loss of generation capacity due to lack of water supply for cooling or other production processes, particularly hydrogen Failure of gas pipes due to ground shrinkage in prolonged periods of drought
Wind strength & wind regimes, storminess & occurrence of storm events	Highly uncertain	Highly uncertain	Potential large-scale and coordinated loss of wind generation during wind droughts Loss of generation capacity due to damage during storm events; potential large-scale and coordinated loss of wind generation during high wind speed shutdown of turbines Loss of network capacity due to damage in storm events (Offshore) Destabilisation or degradation of mechanical systems and structures, reduced energy yields and operating periods, loss of integrity of foundations and cabling systems caused by loading and sediment transport across the sea bed, and impeded access for maintenance and inspection activities

Recommendations

Key recommendations

- Publish a comprehensive long-term strategy for the delivery of a decarbonised, resilient, power system by 2035.
- Clarify urgently and formalise the institutional responsibilities of the Future System Operator, Ofgem and Ministers, for strategic planning and delivery of the decarbonised, resilient system.
- Conduct a review of governance arrangements for resilience to climate hazards in the energy system, to ensure they are fit for the new expanded and more diverse low-carbon system given increasing societal reliance on electricity.
- Develop a long-term cross-sectoral infrastructure strategy to adapt and build respectively the distribution of liquid and gaseous fuels, electricity, CO2 and heat networks over the next decade.
- Identify a set of low-regret electricity and hydrogen investments that can proceed now.
- Create a Minister-led infrastructure delivery group, advised by the new Electricity Networks Commissioner, to ensure enabling initiatives for energy infrastructure build are taken forward at pace, and necessary policy changes are implemented across the UK, to deliver a decarbonised and resilient power system by 2035.
- Through the Review of Electricity Market Arrangements, develop a strategy as soon as possible on market design for the medium- to long-term for a fully decarbonised, resilient electricity system in the 2030s and onwards.
- Fast-track the development of new business models for hydrogen transportation and storage infrastructure, with a view to keeping options open for larger scale hydrogen use by 2030.

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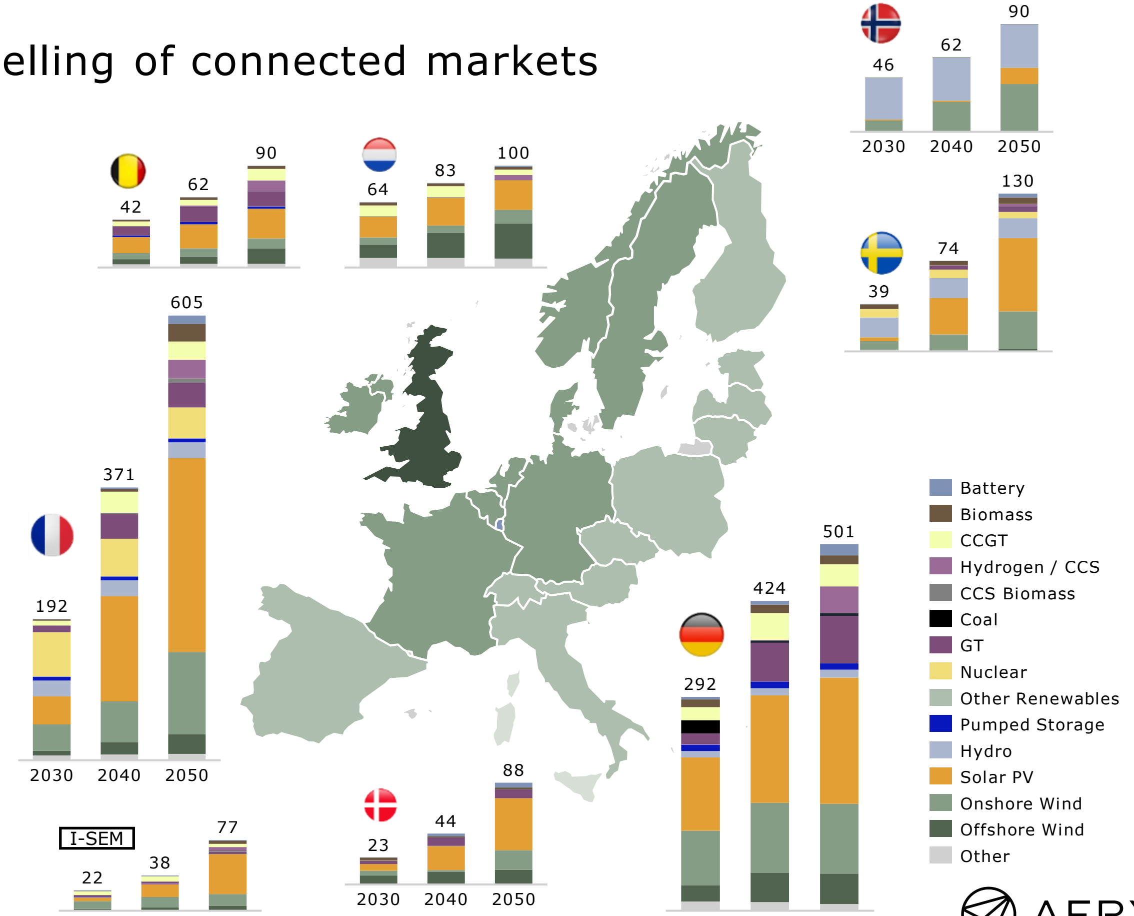
Annex

EUROPEAN CONTINENTAL INTERCONNECTION

AFRY included detailed modelling of connected markets

- Full hourly modelling of the European system was included alongside the modelling of the GB market
- Interconnector flows were given an endogenous treatment in the modelling
- Interconnector capacity was determined based on government policy and expected projects from Cap and Floor allocation, and knowledge of other potential new projects.
- Continental markets were given an EU wide decarbonisation target, individual modelling of region specific renewable potential for capacity and generation
- This ensured interconnectors in GB were not over-optimised:
- Neither excess import capacity at peak, nor 100% reliability during low wind periods



Our proprietary power modelling platform, BID3, simulates dispatch of electricity and hydrogen supply and demand

BID3 OVERVIEW

- BID3 is AFRY's multi-market dispatch model that uses advanced mathematical techniques to model the dispatch of supply and demand, market prices, capacity evolution, and all other important features of energy markets
- Features of the BID3 platform include:
  - the 'Auto Build' module, used for scenario creation with optimal least-cost new-build, retrofitting, retiral and mothballing
  - sophisticated treatment of demand response and energy storage, allowing simulation of flexible load such as electric vehicles and heat, and detailed modelling of various energy storage technologies
  - hydrogen and power sector coupling including hydrogen production, storage, transmission between zones, and consumption
  - geographic resolution, which allows BID3 to give proper representation to the spatial constraints within the GB power and hydrogen sectors
- Each future year is simulated at hourly resolution under 5 historical weather patterns to reflect a range of possible outcomes for uncertain, weather-driven features of power systems.

KEY FEATURES

BID3
Electricity Market Model

- Multiple weather patterns
- 8760 hourly resolution
- All flexibility technologies
- Transmission constraints and network expansion
- Granular endogenous investment module
- Endogenous system operability constraints
- Realistic treatment of interconnector and DSR capabilities

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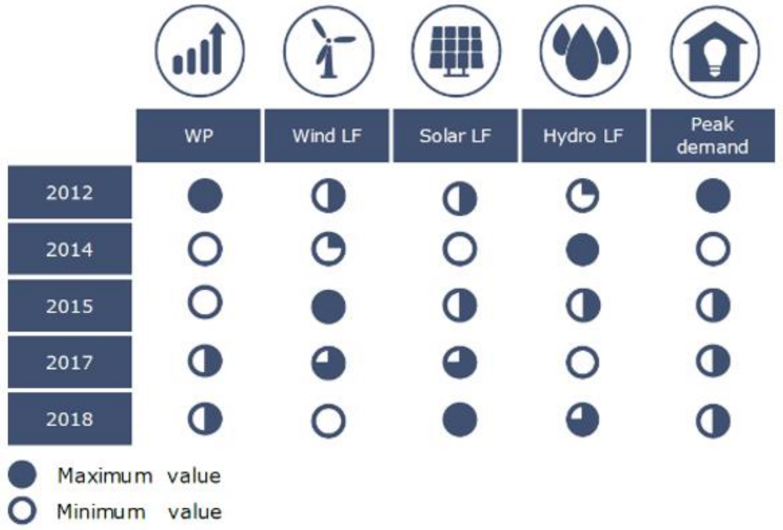
ÅF PÖYRY

AFRY models each future year five times using five different historical weather patterns for our core scenarios

- AFRY have selected our weather patterns based on analysis of up to 30 years of historical weather data across Europe
- We have chosen these 5 weather patterns to have:
  - 1 cold, dry, still year (2012) that gives rise to tight capacity margins
  - 2 moderate weather years (2014, 2018)
  - 2 warm, wet windy years (2015, 2017)
- Dispatch modelling is performed for each of these 5 weather patterns for each future year, but investment decisions are taken based on mean revenues and costs per future year
  - Whilst also maintaining security of supply across each weather year individually
- We also constructed 2 “Frankenstein” weather years to stress test the 2035 system with (a) and overall low wind and (b) an extended wind drought of over 1 month.

AVERAGE WEATHER PATTERNS BY YEAR

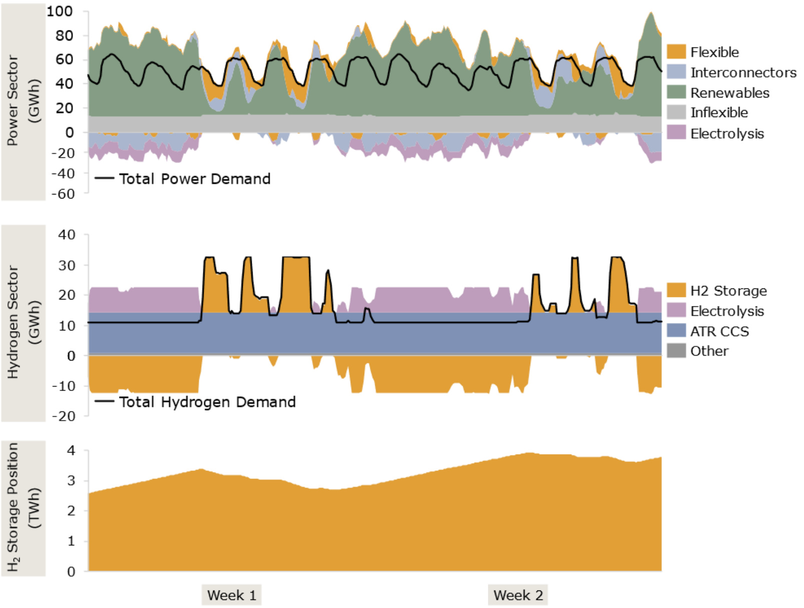


BID3 considers the interactions and concurrent action in the power and hydrogen sectors

BID3 KEY MODELLING FEATURES

- Modelling of power and hydrogen sectors
- Optimises build of electrolysers, hydrogen storage, and hydrogen fired generation
- Hourly dispatch of energy in both sectors
- Simulates intermittent renewable generation over multiple weather years
- Hourly energy flows and conversions, through electrolysis and hydrogen to power
- Models hydrogen storage, injection and withdrawals
- Models geographical zones and development of power and hydrogen transmission
- Hourly pricing of power and hydrogen
- Cash flow analysis of hydrogen assets with hourly captured prices and optimised dispatch

POWER AND HYDROGEN INTERACTIONS



Hourly snapshot of interactions and concurrent action in the power and hydrogen sector during a fortnight in June 2035, using 2012 weather patterns

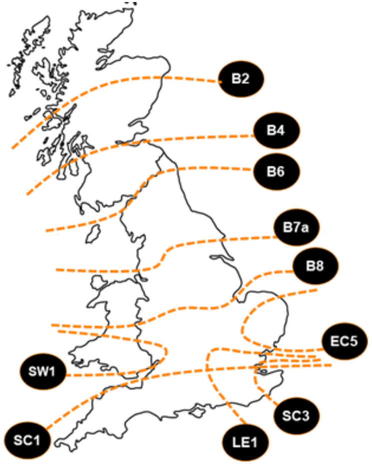
Locational needs for flexibility were considered for 11 energy zones considered within the modelling

BID3 LOCATIONAL MODELLING

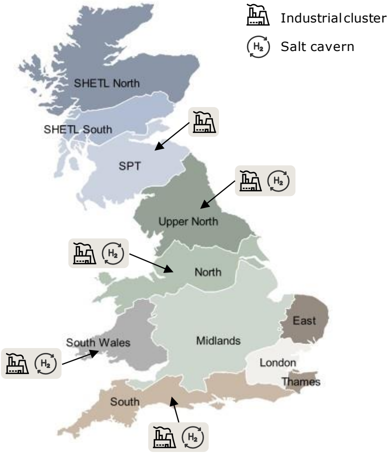
- To assess locational flexibility needs and to incorporate the cost of transporting power and hydrogen, the modelling considers GB as 11 separate energy zones determined by constraints in the power transmission network at present.
- The viability of utilising hydrogen for storage is zonally assigned in order to better understand the locational feasibility of different technologies.

Power transmission

- Demand and renewables disaggregated between zones
- Transmission capability across boundaries determined short term by NG ESO publicised plans for reinforcement
- Further reinforcement optimised based on expected costs of transmission boundary capability upgrades
- Flexibility investment options alternatives to grid investment



GB transmission constraint boundaries in AFRY modelling



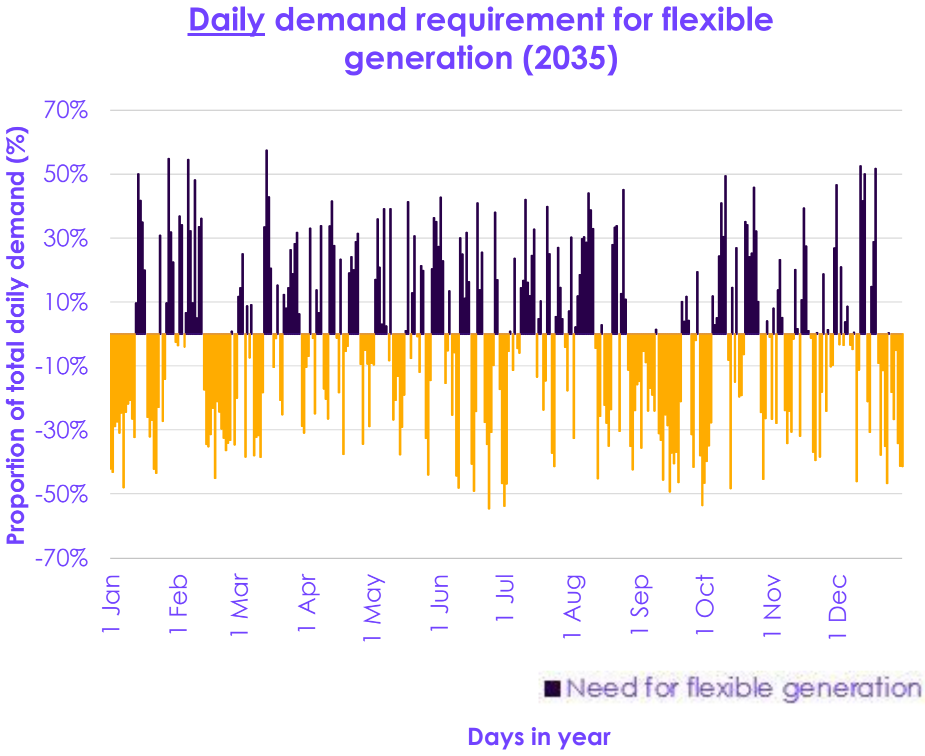
GB hydrogen zones

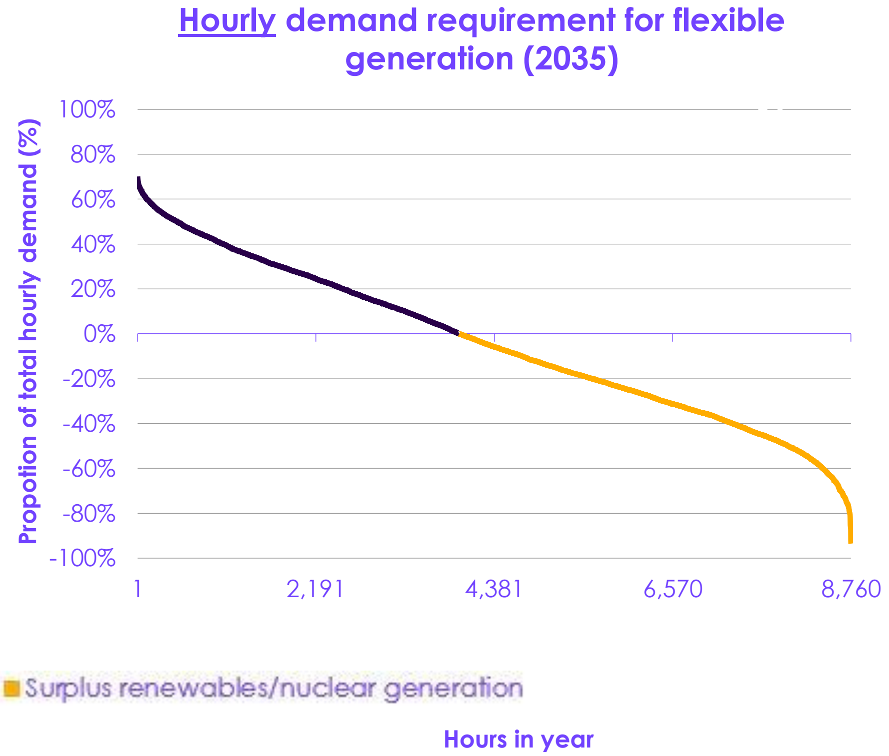
Hydrogen transmission

- Hydrogen demand disaggregated between industrial clusters and geographic zones
- Blue hydrogen CCS and geological hydrogen storage limited to specific regions based on require characteristics for storage
- Hydrogen pipelines capacity optimised by the model
- Electrolysis and H2 turbines deployed based on locational needs

Significant flexible capacity is required

Our modelling shows flexible options required on about half of the days/hours in 2035 – covering short to longer-term

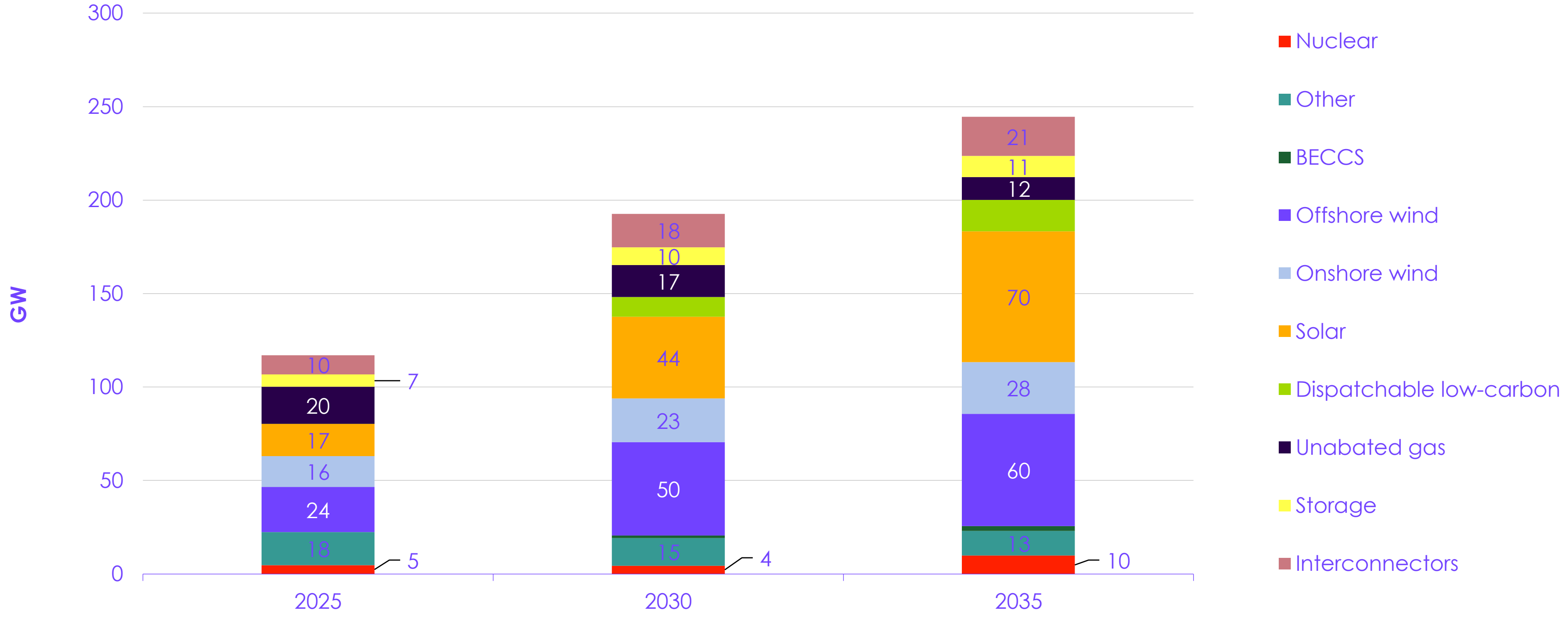




■ Need for flexible generation ■ Surplus renewables/nuclear generation

Changes in electricity capacity

Low-cost variable renewables, especially offshore wind, the backbone of the future system, supplemented by complementary solutions



Source
AFRY (2023) *Net Zero Power and Hydrogen: Capacity Requirements for Flexibility*

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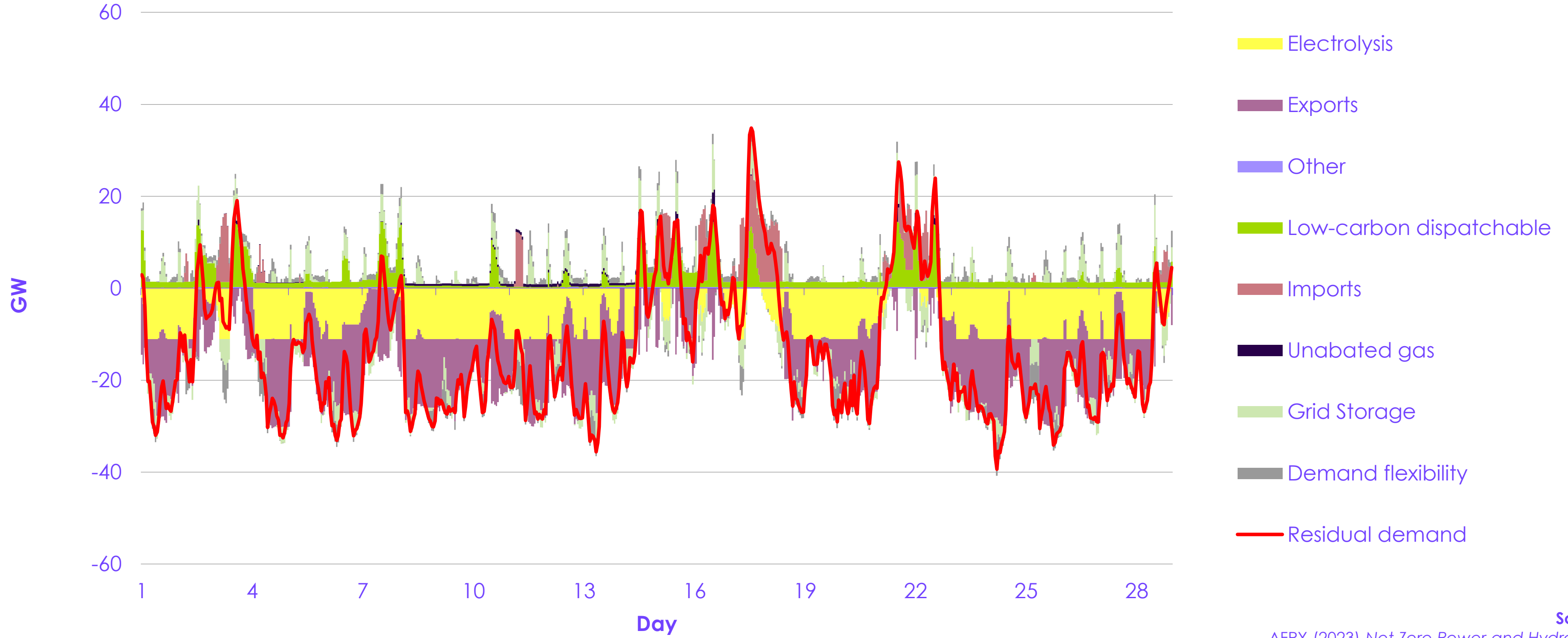
Tools to complement variable renewables and nuclear

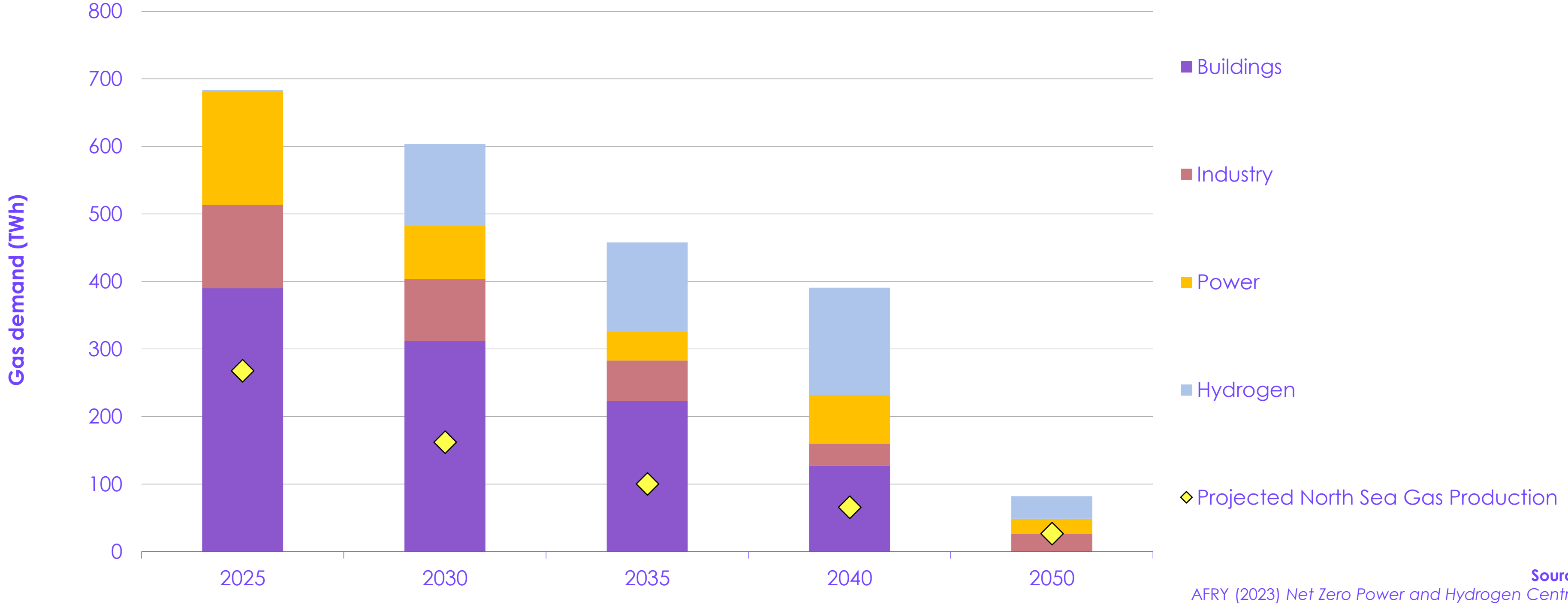
Portfolio of low-carbon flexibility solutions to bridge the gap in 2035 – four-week period of **lowest** residual demand



Source
AFRY (2023) *Net Zero Power and Hydrogen: Capacity Requirements for Flexibility*

Annual GB gas usage declines rapidly

Falling demand for fossil gas as we decarbonise power, buildings, industry – but imports still required



Source
AFRY (2023) *Net Zero Power and Hydrogen Central Scenario*, CCC (2020) *Sixth Carbon Budget Balanced Pathway*; NSTA (2022) *August 2022 oil and gas production projections*

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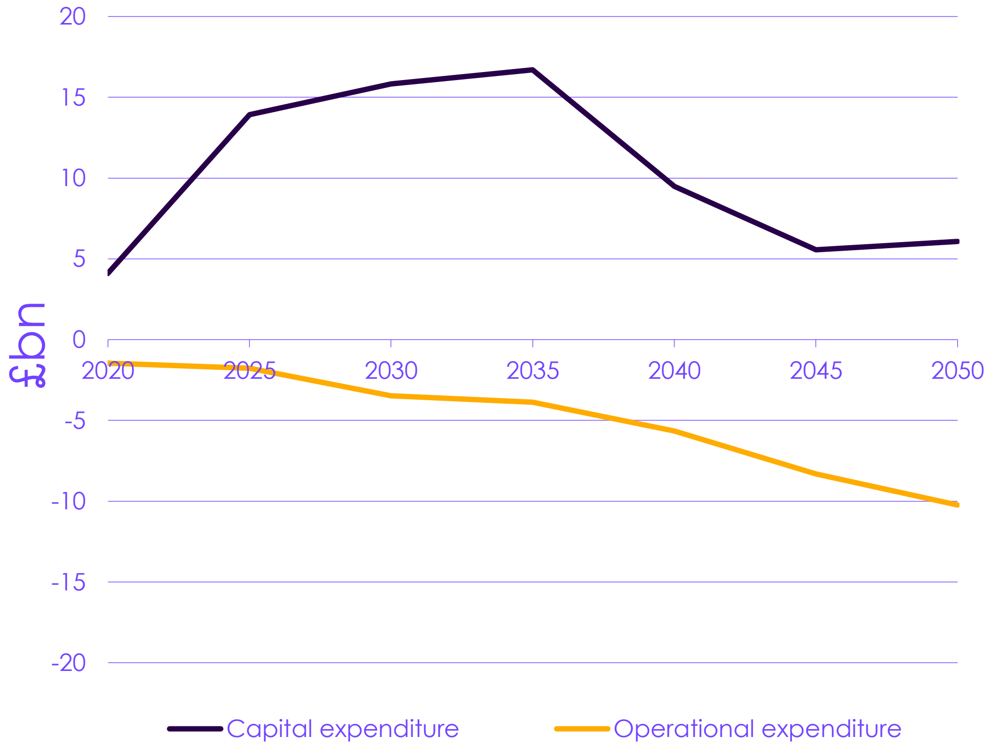
We must design resilience in now

Otherwise, we risk locking in future weather-related failure

Additional investment requirements for electricity generation in the CB6 Balanced Pathway (2020-50)



Source: CCC Sixth Carbon Budget

The solutions are clear and actionable

We need to design and build the future energy system so that it can continue to operate under these changing conditions

- Future climate impacts must be reflected in site selection and design, as well as in maintenance and life extension of existing assets.

- Minimum resilience standards are needed to enable this, covering regulated parties and all relevant climate hazards identified in the UK Climate Change Risk Assessment (CCRA).

- Changes in demand due to climate change need to be factored into future planning.

- Changes in weather hazards which remain uncertain are challenging but need to be planned for, such as wind droughts and the implications of reduced water availability for hydrogen production.

- Further research is needed to improve understanding of how climate change will alter key weather hazards that will impact the energy system. A more systematic assessment of risks posed from cascading impacts due to failures of the energy system is also needed.

- Key enablers to achieve these outcomes include clearer governance remits for resilience, better indicators and incorporation of resilience into Net Zero investment decisions.