November 2021

Net Zero Market Reform

Case for Change and Market Design Options Assessment Framework

nationalgridESO

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Foreword

I am delighted to publish an update on National Grid ESO's Net Zero Market Reform programme of work. Markets are key to ensure safe and reliable electricity supply at an efficient cost to consumers and we know they are going to play a critical role on the road to net zero.

Kayte O'Neill
Head of Markets, National Grid ESO

Markets need to take us from where we are today to a future energy system that looks very different across supply, demand and networks. The ESO has a privileged role at the heart of the energy system, which means we are uniquely placed to assess how markets need to be reformed over the longer term to achieve net zero.

Our Net Zero Market Reform project is different from other market reform projects we have previously undertaken as we will have a longer-term focus out to 2035 and 2050, and we will look at the full suite of GB electricity markets and policies, not just those run by ESO. The project was established in early 2021, and by April 2022 we aim to share recommendations on the future direction of market reform.

This publication provides an update on the work carried out so far and sets out plans for the remainder of the project. We present our findings of the key challenges identified from our case for change modelling and stakeholder engagement, and our proposed framework for assessing market reform options in the next phase.

Input from our stakeholders through our co-creation workshops, webinars and discussions has been crucial throughout this project so far. As we move into this next phase of more detailed assessment of reforms, it is vital that we continue to work even more closely with our industry partners, as well as with Ofgem and BEIS. I look forward to these discussions over the coming months.

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Introduction

The Net Zero Market Reform project is exploring how GB electricity markets can support a carbon-free electricity system by 2035, and a net zero economy by 2050, at lowest cost. There is growing industry sentiment that the existing market design requires reform for a future of zero marginal cost generation, volatile supply, and mismatches between where electricity is generated and where it is consumed. The ESO is committed to facilitating net zero operation by 2025. Net Zero Market Reform is a broader workstream considering how electricity markets need to change from 2030 onwards to meet the long-term challenges facing the GB electricity system.

This document sets out our progress to date: it draws together the results of modelling analysis undertaken by external consultants with insights from ESO experts and external stakeholders. We identify the key areas of market design under consideration for reform, our framework for assessing the different design alternatives and the list of options we are taking forward for detailed consideration in our next phase of work. The final output in Spring 2022 will be a set of recommendations on how electricity markets could be reformed.

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Project Overview

January 2021 | April 2021 | November 2021 | April 2022

Phase 1:
Scoping and Stakeholder Landscape

- High level analysis of GB market landscape
- International case studies
- Project scope definition

Phase 2:
Case for Change and Identification of Options

Case for Change

Modelling inputs

3 net zero scenarios for supply and demand → Weather data over 10-year period (2009 – 2019) → 5 future snapshot years (2025, 2030, 2035, 2040, 2050)

Hourly dynamic dispatch model*

Modelling outputs (for 5 snapshot years)

Supply and demand profiles → System characteristics and requirements → Profitability analysis

→ **Identify key challenges for net zero markets**

Identify Solutions

- Define objectives of net zero markets and assessment criteria
- Define market assessment framework
- Identify options for assessment

→ **Assess options against criteria; shortlist taken forward to Phase 3**

Phase 3:
Assess Shortlisted Options

- Detailed assessment of shortlisted options against criteria
- Develop packages of options and assess coherency
- Present recommendations and develop high-level roadmap

Ongoing discussions with industry stakeholders and trade associations

*Developed by consultancy partner LCP; for further information on modelling approach see Appendix.

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The Case for Change in GB Electricity Markets

Introduction

During the second phase of our Net Zero Market Reform project, we have developed a more detailed understanding of the medium- to long-term issues facing the electricity system.

Modelling was undertaken on behalf of the ESO by consultants LCP for five snapshot years (2025, 2030, 2035, 2040, 2050) for the three net zero compliant Future Energy Scenarios (FES). The modelling illustrates potential electricity market outcomes if the existing arrangements were to remain in place.
It provides a picture of potential future system imbalances and key investment drivers for energy assets, such as wholesale prices, in addition to load factors and capture prices for different generation technologies.

Engagement with internal and external stakeholders focused on the areas of Investment, Flexibility and Location to build a broad picture of current and emerging issues facing asset developers and operators, consumers, suppliers, investors and other market participants.

Taking this analysis together, we have identified three major challenges for markets to address on the road to net zero, as shown on the Venn diagram.

The following section provides further detail on each of these three challenges. There is significant overlap between the three. The interactions and interdependencies between the challenges inform how we frame our assessment of market design reforms.

There is a need to **invest** at unprecedented scale and pace

There is a need to manage dramatic energy imbalances with **flexible and firm technologies** across both supply and demand

There is a need to incentivise assets to **locate** and **dispatch** where they can minimise whole system costs

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The Investment Challenge

There is a need to invest at unprecedented scale and pace.

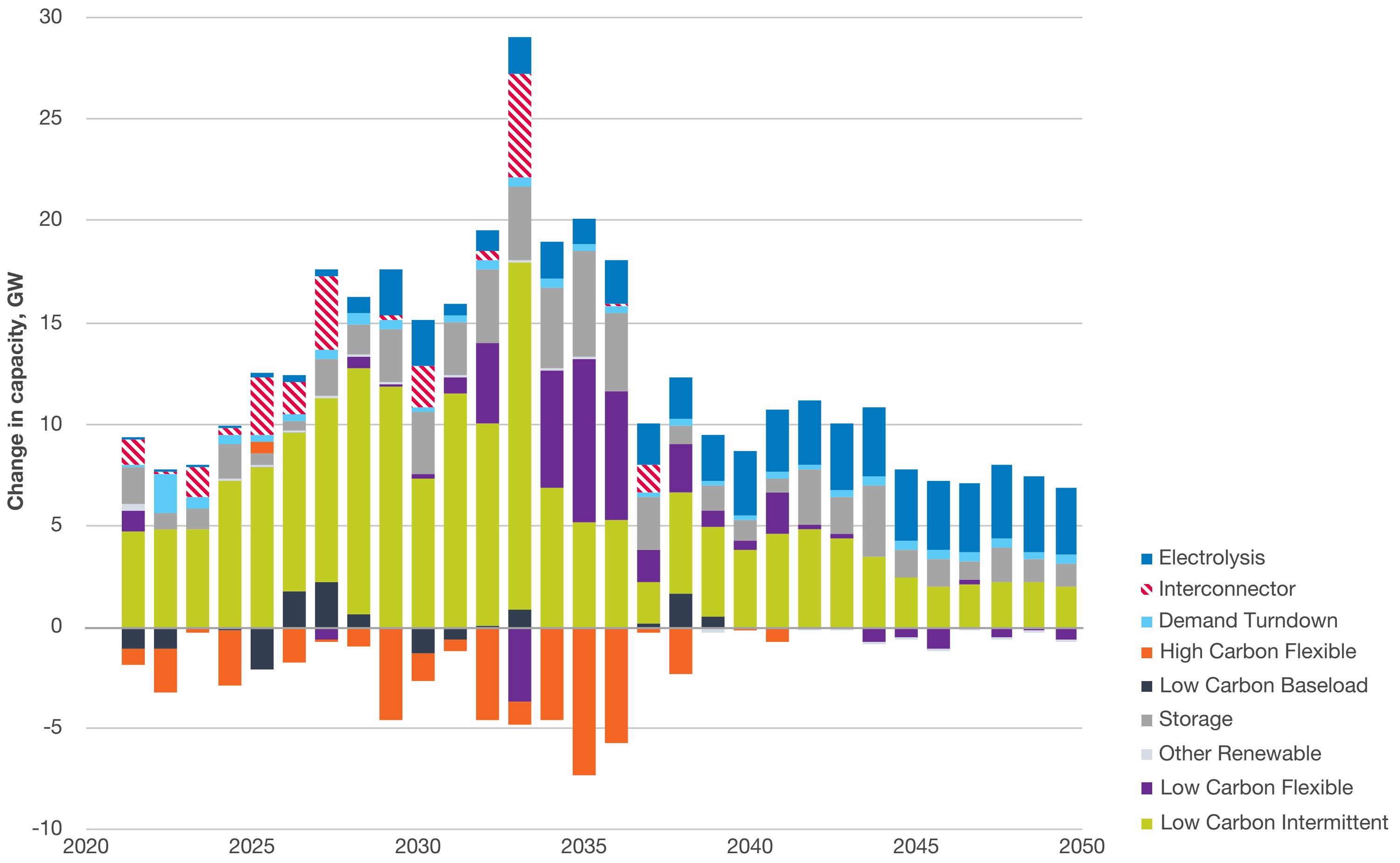
Substantial growth in capacity is required across all scenarios to facilitate the electrification of heat, transport and other sectors in line with government targets. Under the Leading the Way FES scenario, total electricity demand is forecast to increase from c.300TWh/ year today to c.700TWh/ year in 2050. The growth in capacity includes emerging flexible technologies and low carbon generation assets, as well as first-of-a-kind (FOAK) generation technologies including bioenergy with carbon capture and storage (BECCS) and hydrogen which will need to be developed to commercial scale.

Increasing volumes of low marginal cost renewable generation are expected to drive a decline in wholesale prices. This will undermine the financial viability of merchant-only and non-supported generation assets. More volatile prices in wholesale, balancing and ancillary service markets create additional investor uncertainty and risk which puts upward pressure on the cost of capital.

What stakeholders said:
At our case for change workshops, stakeholders voted investor uncertainty as the most significant issue in existing market design arrangements. Lack of investment signals for some technologies, an uneven playing field between technologies, and revenue uncertainty were cited as key barriers to achieving the investment needed for net zero.

Substantial volumes of capacity across new and emerging technologies must be built each year

Capacity Build and Retirements: Leading the Way



Most years have over 10GW of new build with the 2030-35 period seeing a sustained build out of 15GW pa. This presents a significant challenge for the market.

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The Investment Challenge

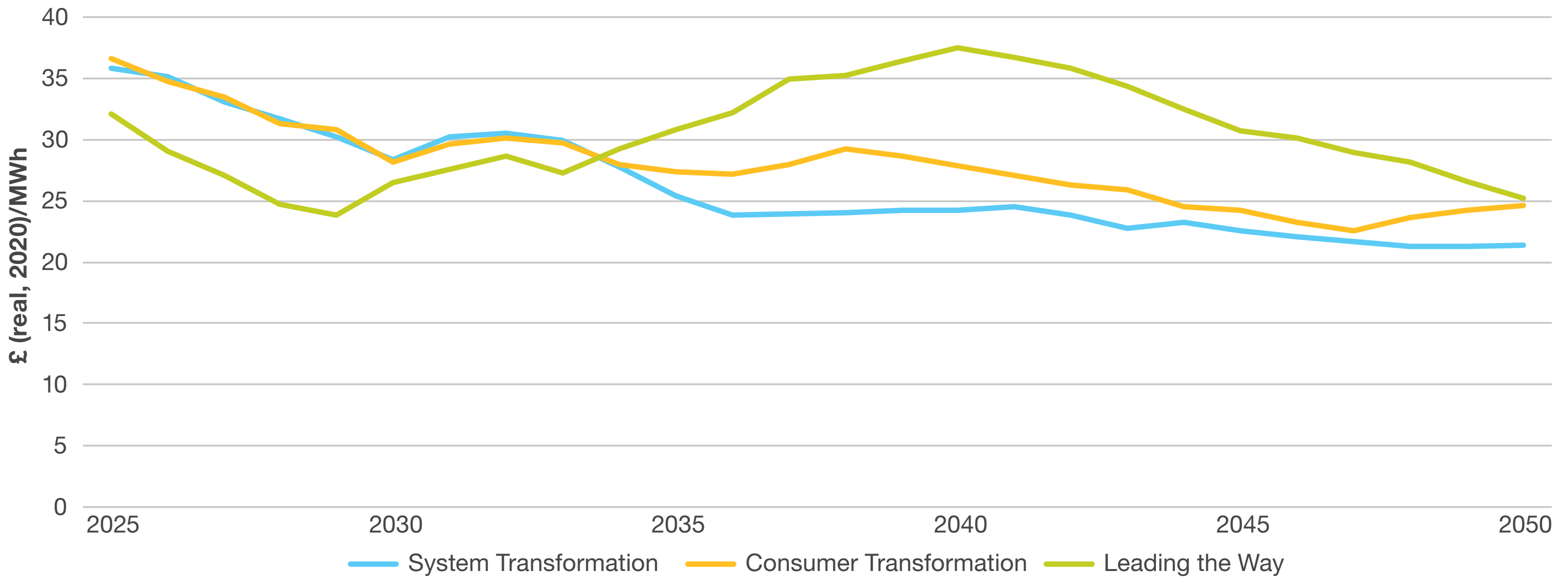
Net Zero Market Design must address:

Declining wholesale price makes investment case difficult for non-supported projects

Growth of zero marginal cost generation drives down the average GB electricity wholesale price for all three scenarios modelled to 2035. Low wholesale prices may also drive existing assets with Contract for Difference (CfD) payments to close prematurely, after their contracts finish. For example, offshore wind capture prices are projected to reach c.£10-£25/MWh, well below typical offshore wind operating costs.

In the Leading the Way scenario, the steep price decline during the late 2020s is reversed during the 2030s as increased flexibility mitigates price cannibalisation (see below).

Baseload wholesale price: All scenarios



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The Investment Challenge

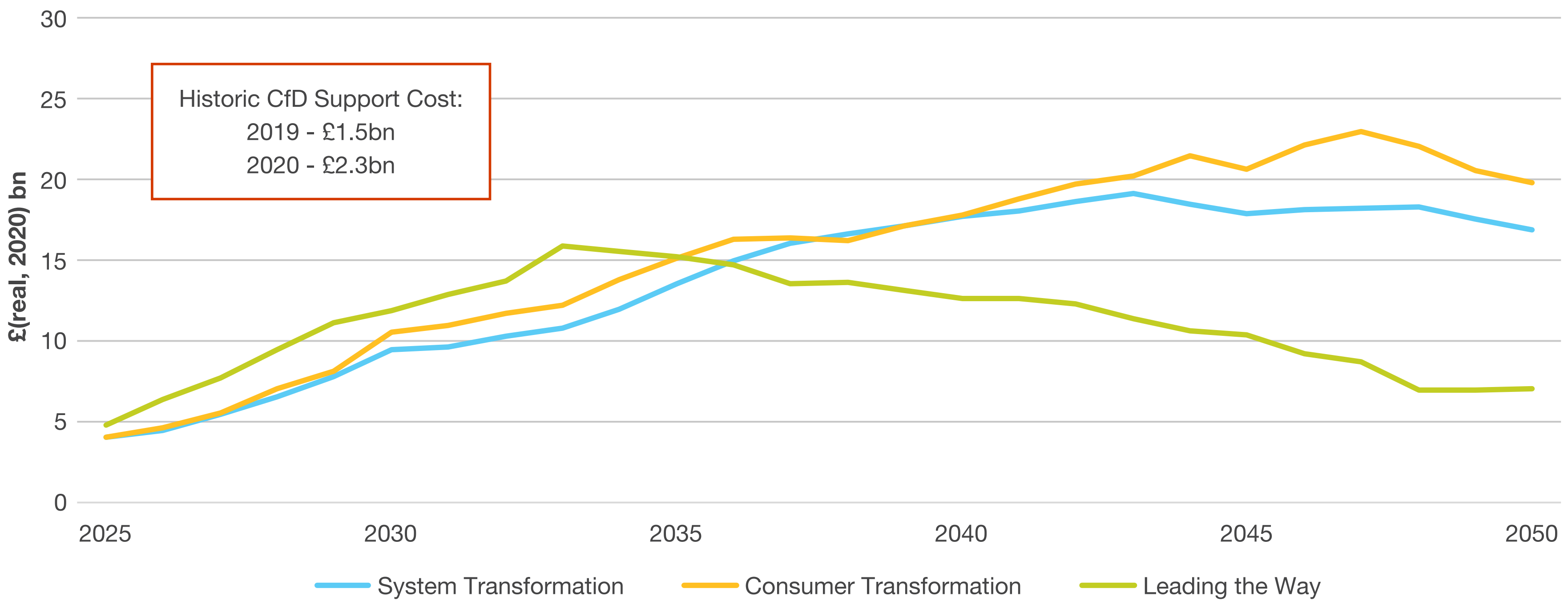
Net Zero Market Design must address:

Increase in total Contract for Difference payments risks market inefficiencies and reliance on ongoing policy commitment

By extending existing arrangements, CfD costs increase from £2.3bn p.a. in 2020 to c£15bn p.a. in 2035. This reflects both greater total qualifying generation and higher price differentials due to falling captured wholesale prices. Sustained support will be required from policymakers to maintain investment momentum.

Generator support payments, recovered evenly over all settlement periods, will represent a growing proportion of retail tariffs. This will result in diluted temporal signals to energy consumers, creating inefficiencies in wholesale markets.

Total Contract for Difference support (£bn): All scenarios



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The Investment Challenge

Net Zero Market Design must address:

Support not in place for key First of a Kind (FOAK) technologies critical to net zero

There are certain emerging technologies (e.g. BECCS, hydrogen and long-duration storage) that are crucial to achieving net zero but are still immature. There are no current support mechanisms to enable these technologies to scale up and reach commercial maturity.

What stakeholders said:
To deal with wind [intermittency], a number of options are available but they need to be low carbon e.g. CCS, long duration storage, interconnection etc. No financial mechanism yet exists for these technologies, and price arbitrage is not enough."

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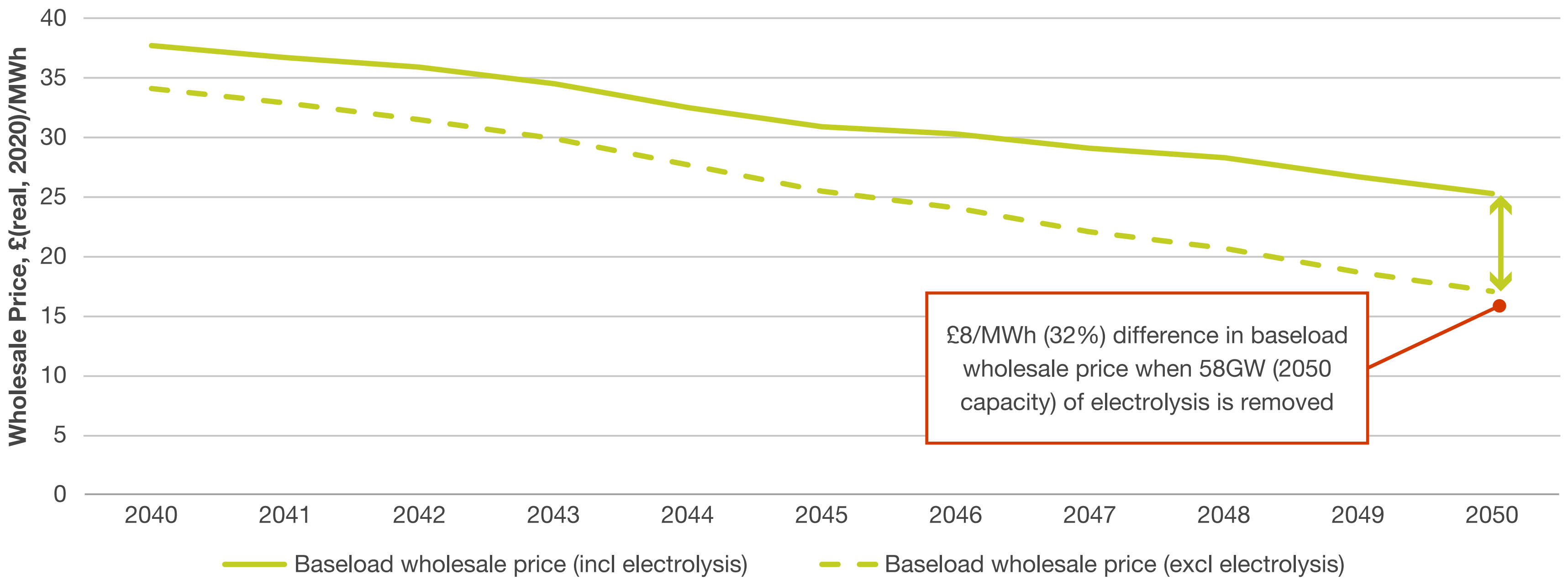
The Investment Challenge

Net Zero Market Design must address:

Lack of flexibility will worsen price cannibalisation

Increasing flexibility mitigates price cannibalisation by reducing the number of periods in which near zero marginal cost generation is price-setting. Key enablers such as smart metering and time-of-use tariff rollout will be critical to exploit the full potential of demand-side flexibility.

Baseload wholesale price with electrolysis sensitivity: Leading the Way



This chart varies electrolysis as a proxy for different levels of demand side flexibility. Reduced wholesale prices will be seen across all scenarios when electrolysis is removed; however, this will vary based on the amount of electrolysis capacity assumed.

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The Challenge of Managing Energy Imbalances

There is a need to manage dramatic potential energy imbalances with flexible and firm technologies across both supply and demand.

The future electricity system will be dominated by intermittent renewable generation. Meanwhile, the electrification of heat, transport and other industry will drive a more variable electricity demand profile. The consequent variability in supply and demand will increase the potential for dramatic energy imbalances that will be managed through a combination of firm and flexible capacity.

Markets must incentivise an optimal mix of low carbon generation, firm and flexible (including demand side) capacity. They must minimise the cost of resolving energy imbalances and maintain security of supply in all weather conditions. Markets must also provide short-term signals for flexible actions that mitigate renewables curtailment when balancing supply and demand.

Note that the energy imbalances illustrated in the following section are derived from the FES, which prioritise determining the right mix of generation, demand and flexibility to ensure the ESO can meet its Loss of Load requirements, and do not principally cost-optimise. This means the figures shown may not accurately reflect the absolute volumes of imbalance in the future system but do reflect the broad direction of travel.

An additional consideration is that the FES scenarios do not include projections for longer-term inter-seasonal storage, which may provide further opportunity to manage energy imbalances cost-efficiently.

> **What stakeholders said:**
> The value of flexibility needs to be established better at all levels."

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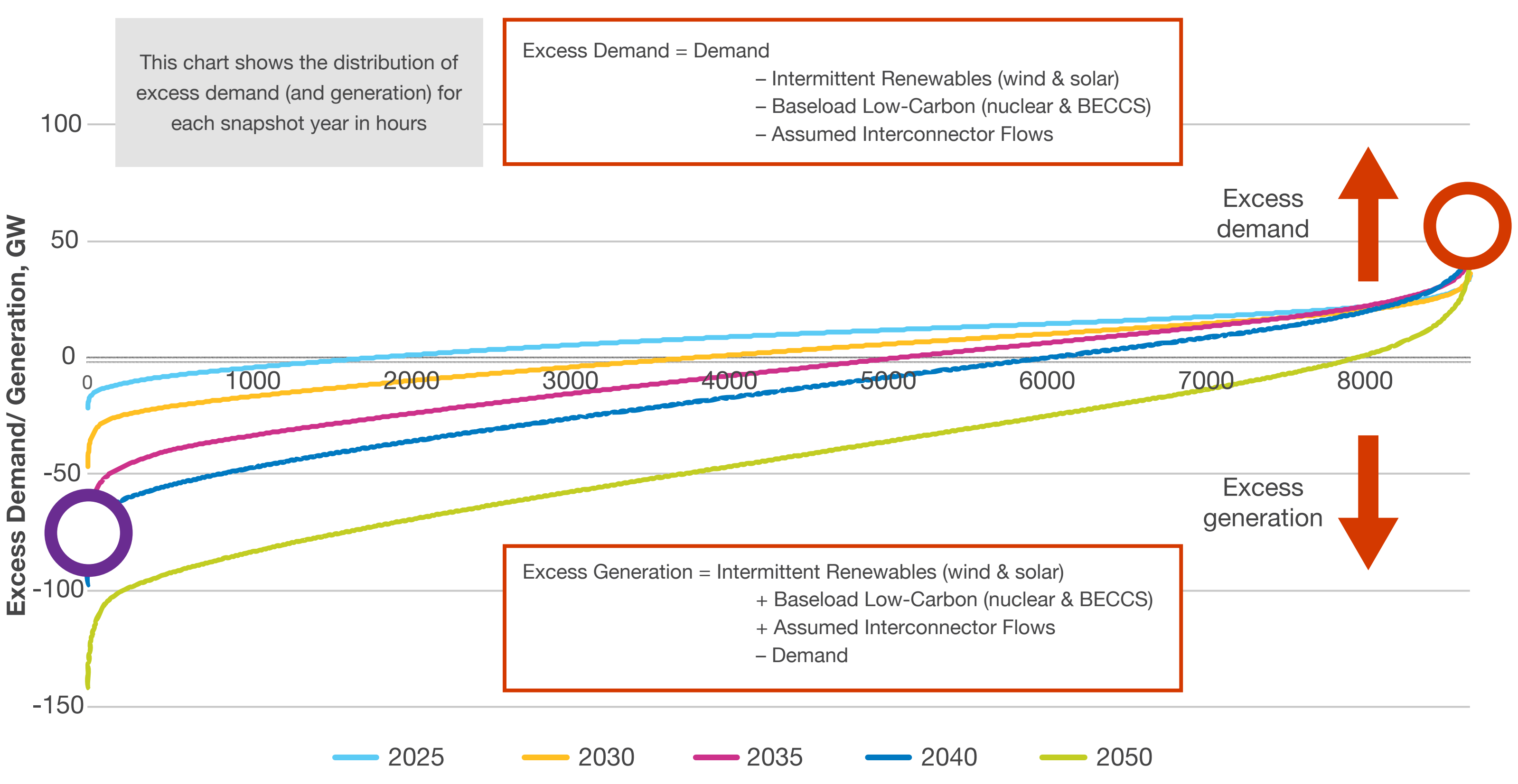
The Challenge of Managing Energy Imbalances

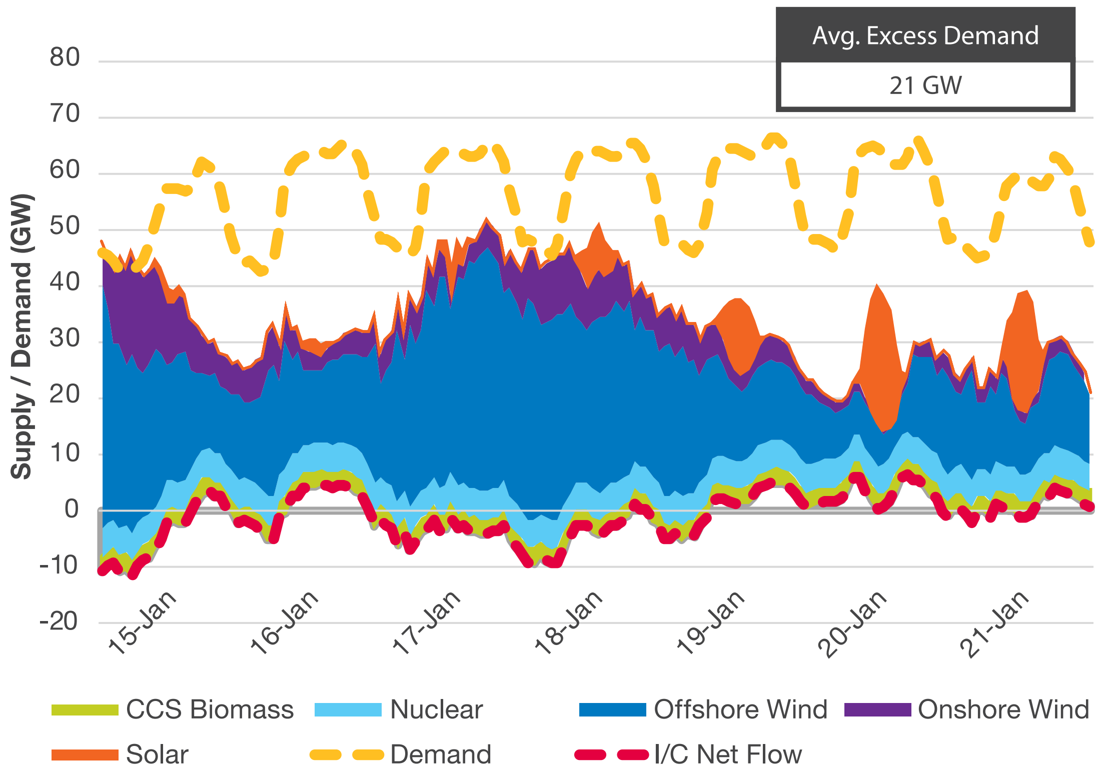
Periods of both excess generation and demand will become more extreme and prolonged

Excess Demand/Generation Distribution (GW): Leading the Way



This chart shows the distribution of excess demand/ generation without flexible capacity, assuming that BECCS and nuclear run as baseload. The proportion of hours with excess generation will increase significantly by 2030 to c.50% of hours. By 2050 this becomes more than 90%. The proportion of excess demand hours becomes less frequent but more extreme.*

Excess Demand Scenario, January 2035: Leading the Way (2017 weather data)



A highly weather-dependent renewable-system will have periods of excess demand when wind and solar generation is low. For a period of one week in January 2035 our modelling shows almost continuous excess demand at an average of 21.1GW. This gap must be filled by flexible capacity including demand side response. Generation stack starts from the net interconnector position.

*Interconnector flows are modelled to align with total annual flows projected in the Future Energy Scenarios.

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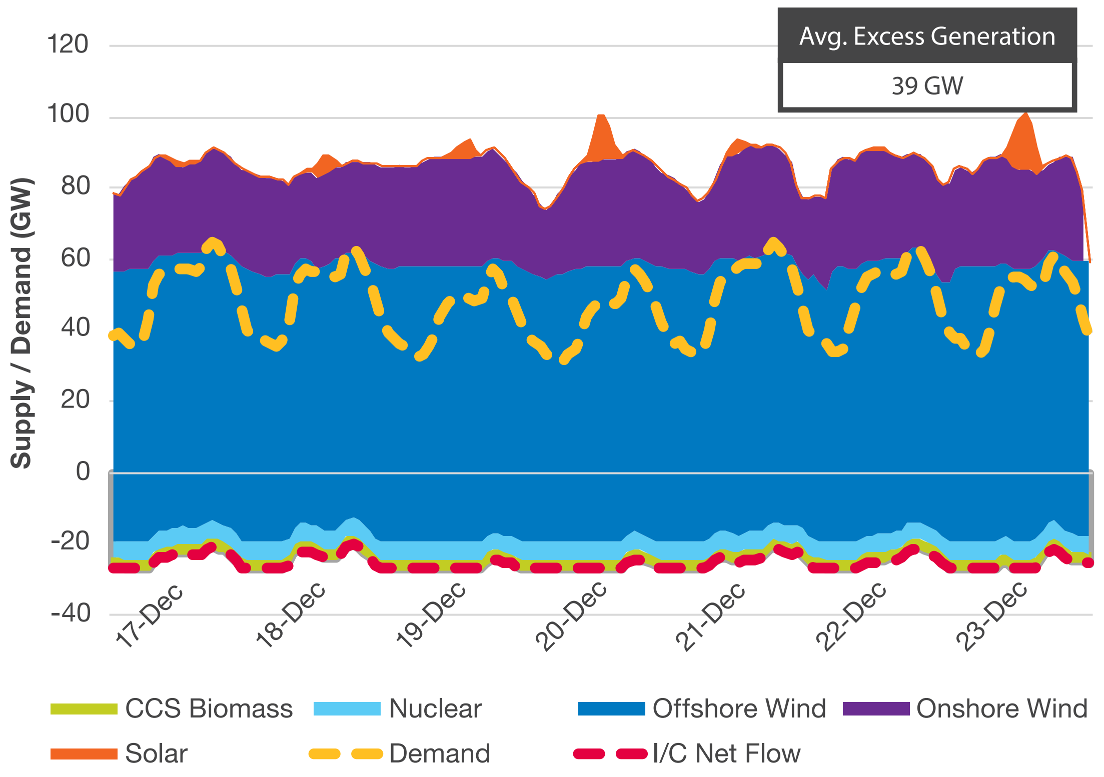
The Challenge of Managing Energy Imbalances

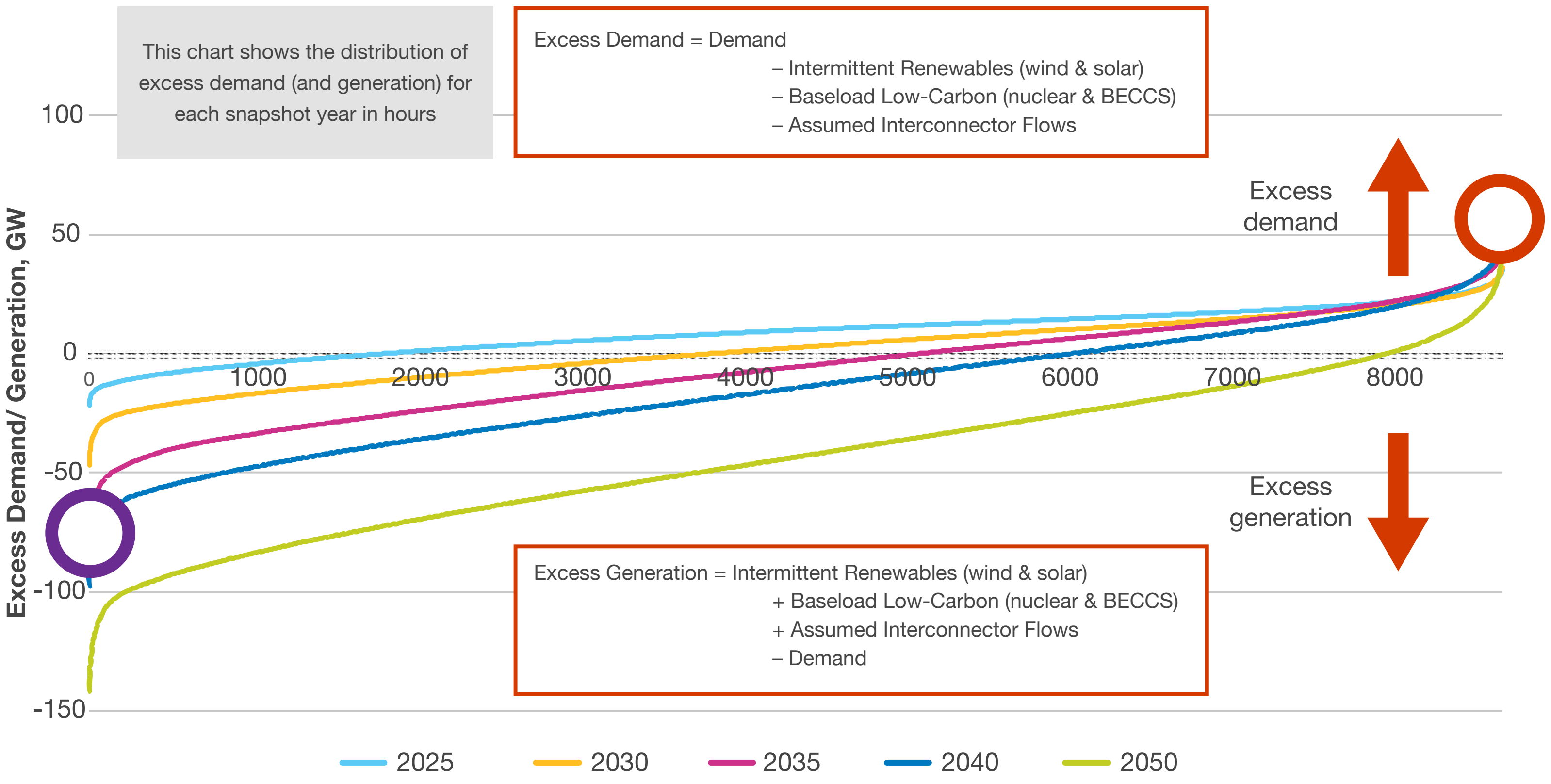
Excess Generation Scenario, December 2035: Leading the Way (2015 weather data)



An intermittent renewable-heavy system will have periods of excess generation during periods of low demand. For a period of one week in December 2035 our modelling shows almost continuous excess generation at an average of 38.6GW. Generation stack starts from the net interconnector position.

Periods of both excess generation and demand will become more extreme and prolonged

Excess Demand/Generation Distribution (GW): Leading the Way



This chart shows the distribution of excess demand/ generation without flexible capacity, assuming that BECCS and nuclear run as baseload. The proportion of hours with excess generation will increase significantly by 2030 to c.50% of hours. By 2050 this becomes more than 90%. The proportion of excess demand hours becomes less frequent but more extreme.*

*Interconnector flows are modelled to align with total annual flows projected in the Future Energy Scenarios.

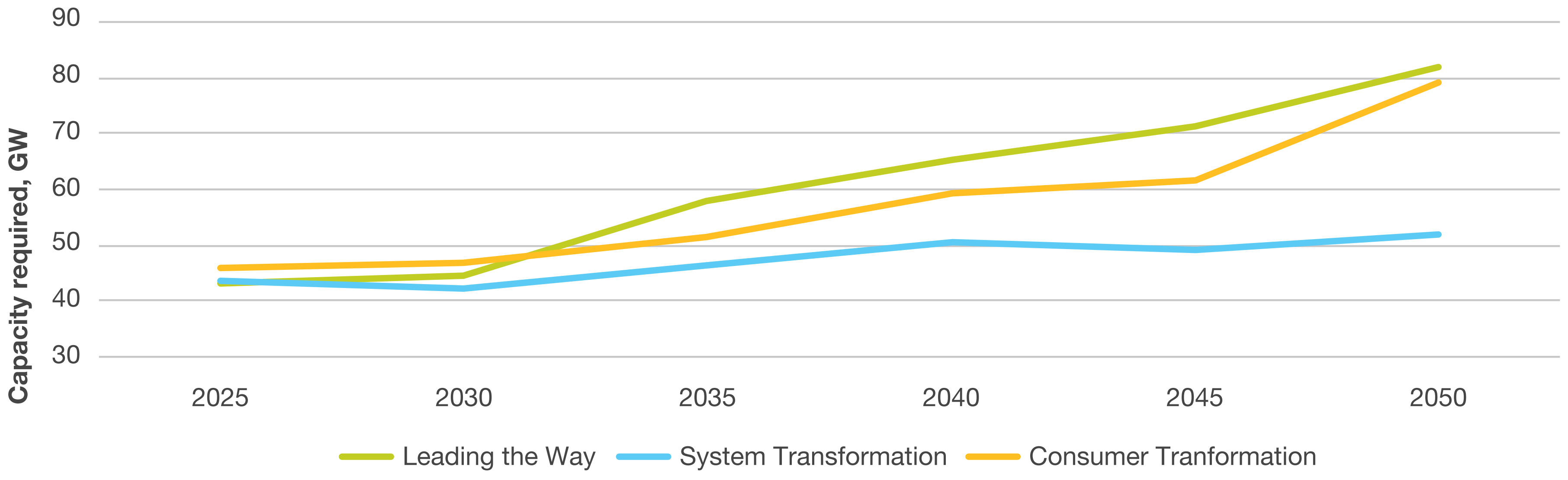
The Challenge of Managing Energy Imbalances

Net Zero Market Design must address:

Increasing volumes of flexible and firm capacity are required to manage periods of excess demand

Periods where generation from renewables, nuclear and interconnectors is insufficient to meet demand will become a far more common occurrence. Firm flexible capacity from technologies including hydrogen and potentially long duration storage are required to manage this generation shortfall.

Equivalent firm capacity required to maintain security of supply*



This chart shows the amount of capacity required from the flexible fleet to meet peak demand, net of wind, solar, BECCS, nuclear and interconnectors.

*Security of supply assumed to be existing 3 hour Loss of Load Expectation.

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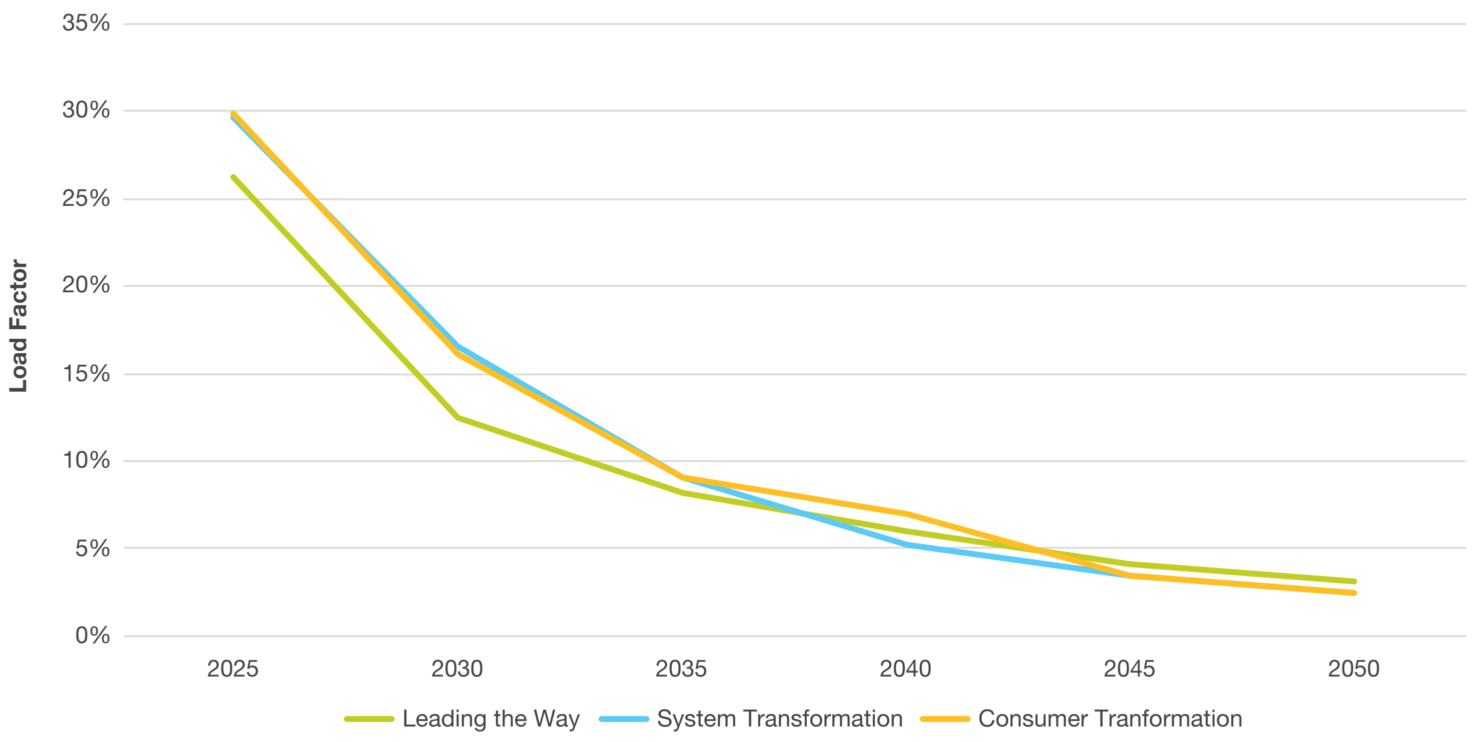
The Challenge of Managing Energy Imbalances

Net Zero Market Design must address:

Load factors for both firm and flexible generation technologies decrease over time, increasing risk for investors

Despite increased system volatility, the periods when firm and flexible capacity are required decrease over time, adding pressure to the investment case for these technologies.

Average load factors of flexible capacity – Leading the Way*



*Flexible capacity excludes variable renewable generation, baseload low-carbon or interconnection.

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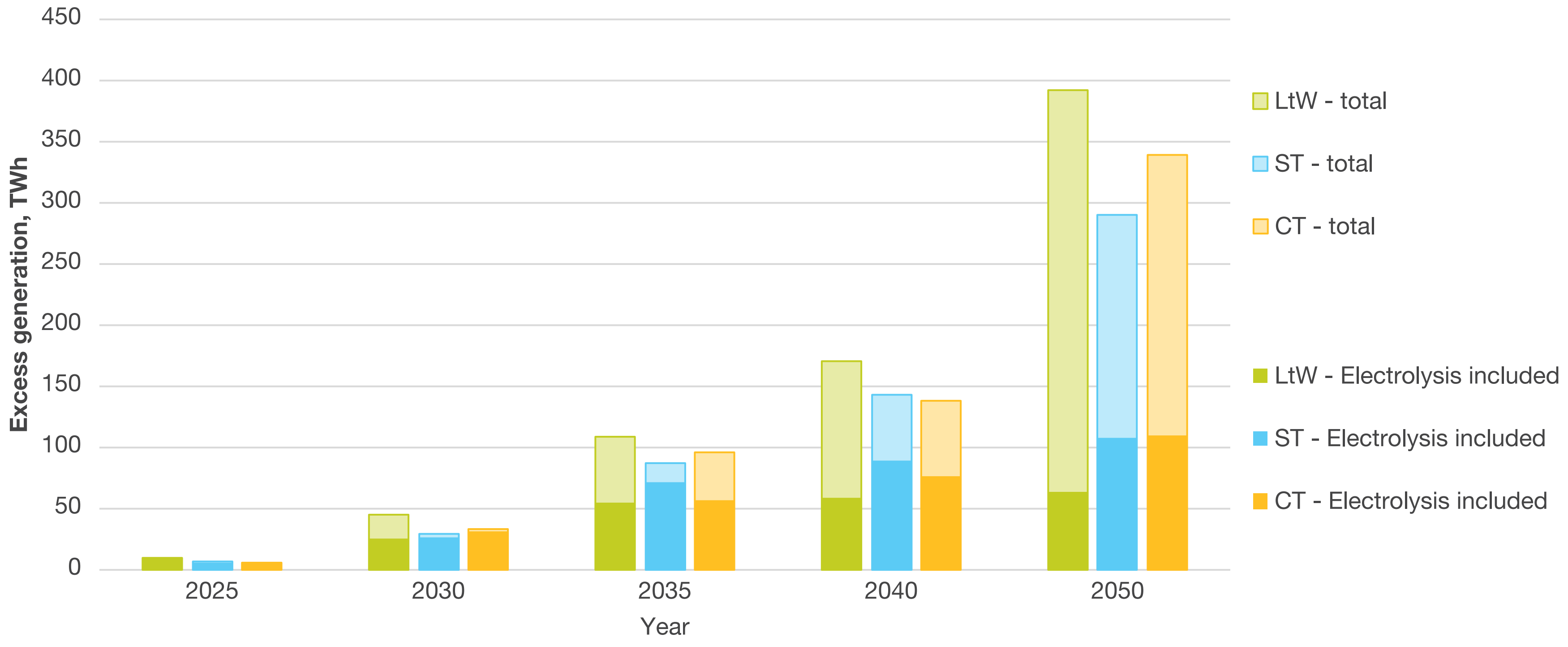
The Challenge of Managing Energy Imbalances

Net Zero Market Design must address:

Without demand side measures, more prolonged and extreme periods of excess generation may lead to substantial renewables curtailment

In high wind periods, large volumes of renewable generation will not be needed, and therefore will be curtailed. The introduction of demand side technologies such as electrolysis can substantially mitigate curtailment of intermittent renewable generation.

TWh of excess generation: with and without electrolysis



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The Challenge of Managing Energy Imbalances

Net Zero Market Design must address:

Revenues for firm and flexible technologies must be bankable to ensure sustained investment

Revenue streams for flexible capacity are volatile and unpredictable. Underlying targets for flexibility can drive investment.

> **What stakeholders said:**
> We need to target certain volumes of different technologies to increase investor confidence otherwise required flexibility won't be there are the right time. We'll see volatile prices as a result."

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The Location Challenge

There is a need to incentivise assets to locate and dispatch where they can minimise whole system costs.

To meet net zero, GB faces a three-way trade-off between exploiting the low generation costs of renewables connecting at the network periphery, controlling network reinforcement costs and minimising network congestion costs.

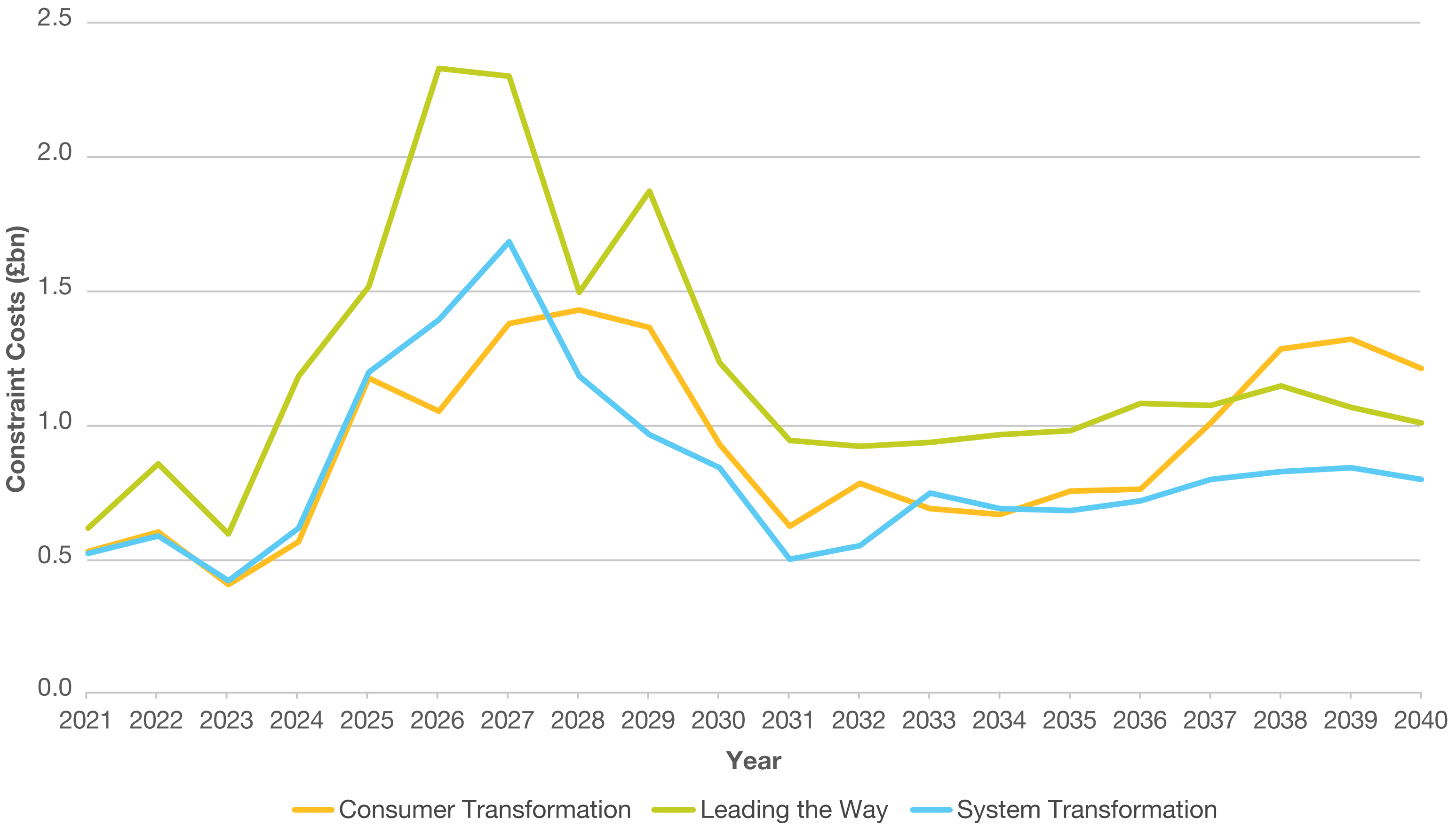
The ESO's current projection of constraint costs (after network reinforcements) to 2040 shows a sharp increase this decade due to renewable generation connecting faster than new transmission capacity can be built. These costs reduce as more transmission infrastructure is built but remain significantly higher than current levels. Efficient locational dispatch signals that account for network congestion close to real time could help to reduce constraint costs.

As more low carbon generation capacity is built, net zero markets must also ensure locational investment signals are both efficient and sufficiently predictable to support assets' investment case.

> **What stakeholders said:**
> There are no long-term accurate forecasts for TNUoS. With increasing scale of generation developments, lead times are longer meaning this is becoming an increasing problem. Coupled with the reducing costs of renewables, TNUoS is a much more important cost than it was in the past."

Latest Network Options Assessment (NOA) projections indicate likelihood of a new normal of higher constraint cost

Modelled Constraint Costs after NOA6 Optimal Reinforcements



ESO projections indicate that congestion costs will rise steeply in the first half of this decade. Costs reduce in the late 2020s, when investments in the transmission network will facilitate the transfer of more renewable generation to southern demand centres.

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The Location Challenge

Key Challenges for Location:

Current price signals do not incentivise efficient locational dispatch

Single GB market means generators and demand are equally likely to self-dispatch wherever they are in the country, ignoring the benefits or costs to the system. This increases constraint costs that are ultimately passed through to consumers.

> **What stakeholders said:**
> The current market can tell you where to locate generation/storage/demand through TNUoS; however, it can't tell you how to operate your assets in real time (e.g. H2 electrolyser, EV charging)."

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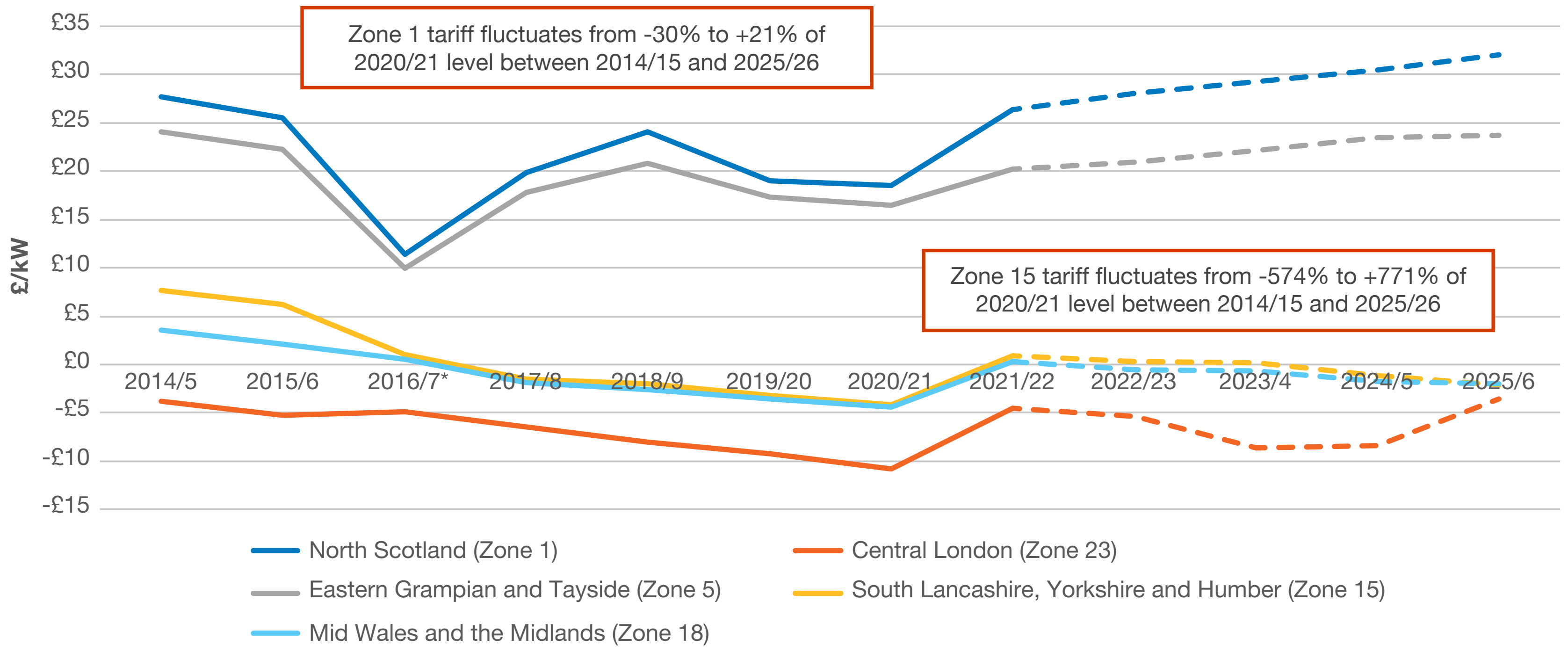
The Location Challenge

Key Challenges for Location:

Volatile and unpredictable TNUoS tariffs may inflate the cost of capital

Wider TNUoS generation charges are both volatile and unpredictable. The inability to hedge these charges may result in inefficient risk premia which may inflate the cost of capital.

TNUoS wider generation tariff for intermittent renewables (historic and forecast)



*Project Transmit CMP 213 which implemented a Year-Round element to generator tariffs was implemented in April 2016. Average Load Factor (ALF) used to illustrate tariffs for 2016/17 was 30% and therefore cannot be directly compared to subsequent years (ALF = 40%).

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The Location Challenge

Key Challenges for Location:

The "size of the prize" of more efficient locational signals grows rapidly over the next decades

Given the enormous growth in demand and new build capacity, the materiality of the economic efficiency of locational signals will grow substantially over the next decades. Every percentage point improvement will equate to a far greater cost saving in absolute terms.

What stakeholders said:
"The locational signal is more important when there is a lot of investment needed as is the case now and for the foreseeable future. Every pound needs to be spent on the most appropriate investment and all relevant cost signals need to be there to ensure the correct decisions are made."

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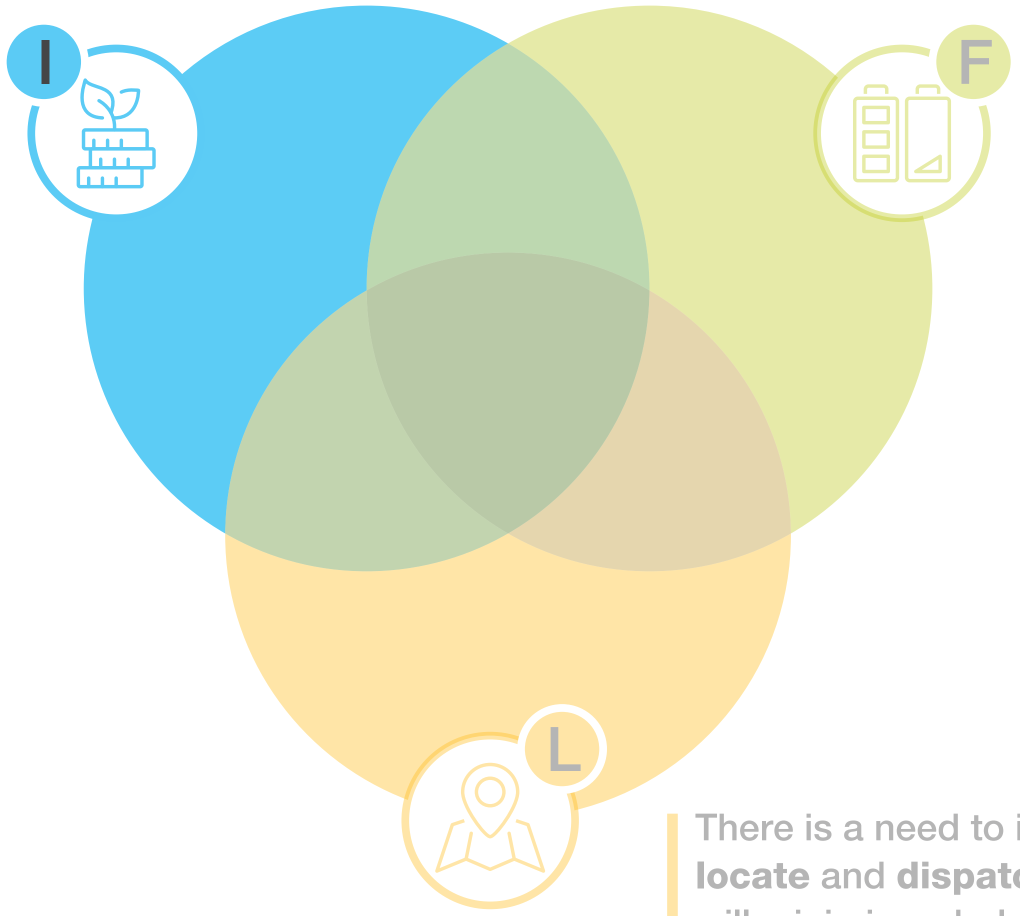
Summary of Key Challenges and Overlaps – Investment

The market design challenges are summarised below. There are areas of overlaps between the challenges, shown in the table, that must be considered.

There is a need to **invest** at unprecedented scale and pace

There is a need to manage dramatic energy imbalances with **flexible and firm technologies** across both supply and demand



There is a need to incentivise assets to **locate** and **dispatch** in locations that will minimise whole system costs

Theme	Issue	Overlap
Investment	Substantial volumes of capacity across new and emerging technologies must be built each year	
	Declining wholesale price makes investment case very difficult for non-supported projects	
	Increase in total Contract for Difference payments risks market inefficiencies and reliance on ongoing policy commitment	
	Support not in place for certain FOAK technologies critical to net zero	F
	Lack of flexibility, including demand side, will worsen price cannibalisation	F

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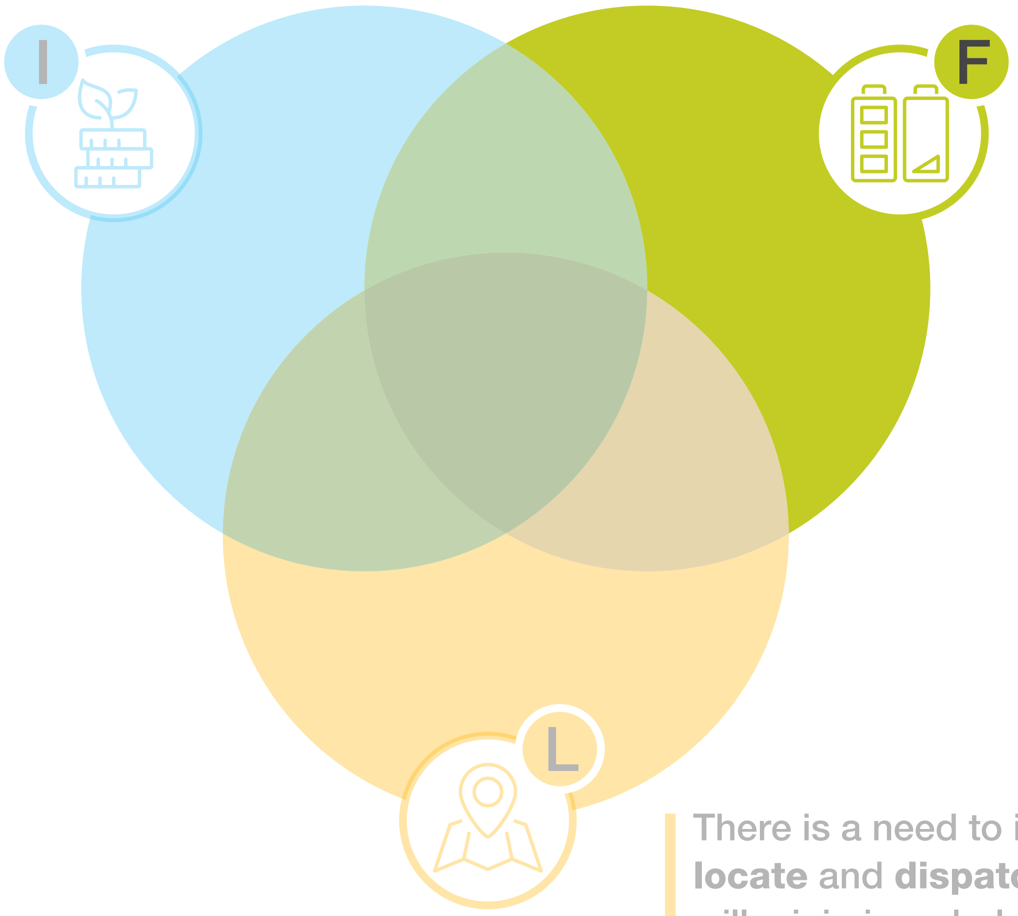
Summary of Key Challenges and Overlaps – Managing System Imbalances

The market design challenges are summarised below. There are areas of overlaps between the challenges, shown in the table, that must be considered.

There is a need to **invest** at unprecedented scale and pace

There is a need to manage dramatic energy imbalances with **flexible and firm technologies** across both supply and demand



There is a need to incentivise assets to **locate** and **dispatch** in locations that will minimise whole system costs

Theme	Issue	Overlap
Managing System Imbalances	Periods of both excess generation and demand will become more extreme and prolonged	
	Increasing volumes of flexible and firm capacity are required to manage periods of excess demand	I
	Substantial renewables curtailment can be mitigated by demand side measures	
	Load factors for both firm and flexible technologies decrease over time, increasing risk for investors	I
	Revenues for firm and flexible technologies must be bankable to ensure sustained investment	I

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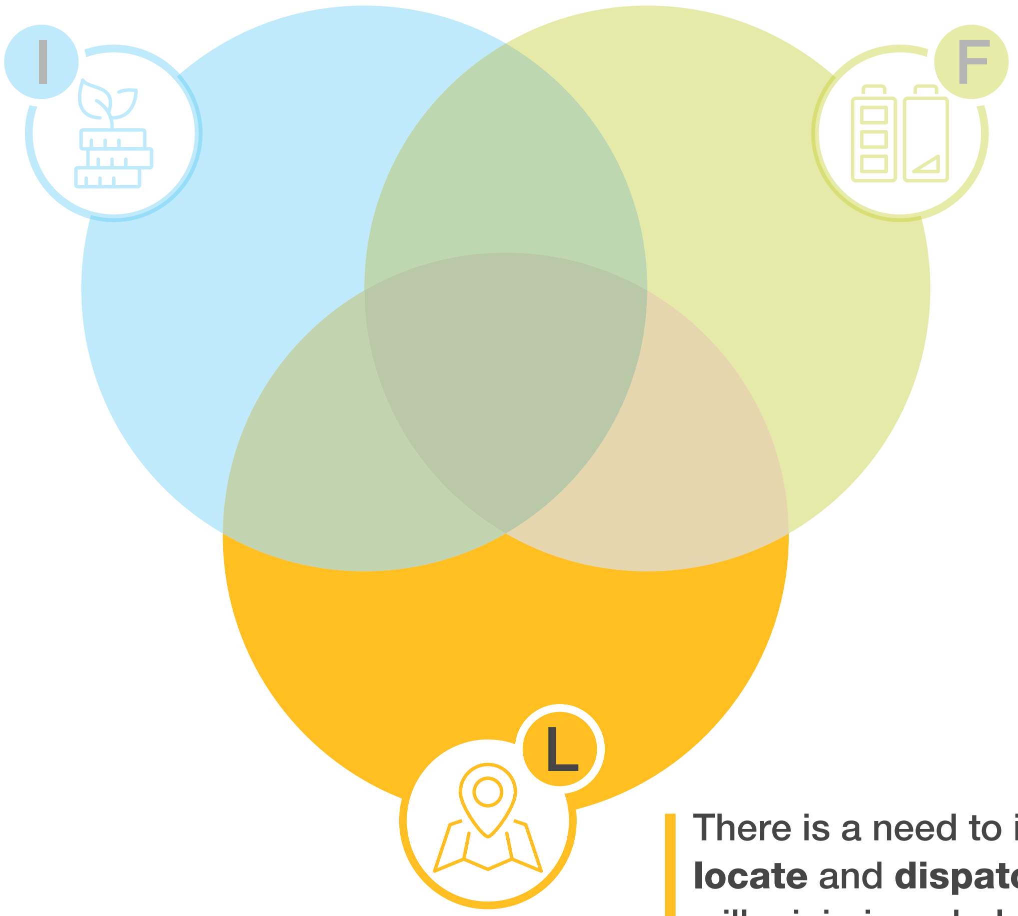
Summary of Key Challenges and Overlaps – Location

The market design challenges are summarised below. There are areas of overlaps between the challenges, shown in the table, that must be considered.

There is a need to **invest** at unprecedented scale and pace

There is a need to manage dramatic energy imbalances with **flexible and firm technologies** across both supply and demand



There is a need to incentivise assets to **locate** and **dispatch** in locations that will minimise whole system costs

Theme	Issue	Overlap
Location	Latest NOA projections indicate likelihood of a new normal of higher constraint costs. Potential for substantial cost reductions through more effective locational signals	
	Current price signals do not incentivise efficient locational dispatch	F
	Volatile and unpredictable TNUoS tariffs may inflate the cost of capital	I
	The "size of the prize" of more efficient locational signals grows rapidly over the next decades	

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Market Design Options Assessment Framework

Introduction

Meeting the challenges set out in the previous section may require substantial transformation of GB's electricity market design. This chapter firstly describes ESO's assessment criteria for effective net zero electricity markets. Next, we outline the framework for how we currently plan to assess different market design elements. For each of these elements, we then identify the main market design options and set out our preliminary scoring of these options against the criteria. This includes our rationale for excluding a few outlier options for further consideration. The scoping of market design options and initial assessment has been supported by Frontier Economics.

Assessment Criteria

To evaluate potential market reforms, we identified 9 assessment criteria for net zero markets. Specific stakeholder events were held to validate that these objectives are broadly agreed upon by industry.

The criteria listed on the right are not weighted, and the order given does not indicate relative importance.

Assessment Criteria:	
Decarbonisation	Provides confidence that carbon targets will be met
Security of Supply	Ensures that adequacy and operability challenges can be met
Value for Money	Ensures that the electricity system (network build, short run dispatch and long run investment) is being delivered efficiently
Investor Confidence	Investors are exposed to appropriate risks (e.g. risks they can manage) and the cost of finance is minimised
Deliverability	Transition from current market design to target design is deliverable in an appropriate timeframe
Whole System	Facilitates decarbonisation across other energy vectors, across connection voltages and facilitates demand-side participation
Consumer Fairness	The costs of the system are fairly shared across all consumers
Competition	Facilitates competition within and across technologies, between generation and demand and across connection voltages
Adaptability	A market design that can adapt to changes in technology or circumstances with limited disruption within a reasonable time frame

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Market Design Elements & Order of Assessment

Based on the findings in our case for change, we identified 8 key elements of market design and categorised these into 2 broad categories: 'Investment' and 'Operation'.

Due to stronger interactions within the two categories, elements under Investment have been assessed separately from Operation. Within each category we have determined the appropriate sequence in which to assess the elements based on their main dependencies. This sequence is reflected in the order in which the elements are presented in the table below. This includes identifying elements as first and second order priorities. The two broad categories are then assessed in parallel.

	First Order Elements		Second Order Elements	
Investment	1 **Low Carbon Central Planning** →	The degree to which the low carbon technology mix is determined by the government. It is assumed that the government will continue to determine the overall low carbon generation requirement.	6 **Low Carbon Support Mechanism** →	The degree to which variable renewables generation is protected from wholesale price volatility.
	2 **Capacity Adequacy** →	The degree to which the firm capacity technology mix is determined by government. It is assumed that government will continue to determine the overall capacity adequacy requirement.		
	3 **Flexibility** →	The degree to which both the overall flexibility requirement itself, as well as the flexibility technology mix, is determined by government. Unlike low carbon and capacity adequacy, the government does not currently determine overall flexibility requirements (e.g. via a flexible capacity target).		
Operation	4 **Location** →	The level of locational granularity in the wholesale electricity market.	7 **Settlement Period Duration** →	How frequently the market for trading and balancing is settled. Reducing the settlement period may help to reveal the additional flexibility value within periods.
	5 **Dispatch** →	Whether physical dispatch is primarily determined by market participants or centrally by the System Operator. Central dispatch can be combined with co-optimisation of ancillary services procurement.	8 **Ancillary Service Market Design** →	The precise nature and volume of balancing services required are a residual outcome of other market design, such as the proportion of flexibility and intermittent renewables capacity on the system. Changes to ancillary service markets over the longer term should therefore logically follow decisions on other market design elements any designed in conjunction with ongoing ESO work in this area.

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Investment Market Design Elements

We have identified the main alternative options for each market design element. These can loosely be represented on a spectrum of greater central planning of the technology mix, to greater market determination of the technology mix outcome.

← **Technology mix centrally planned** — **Technology mix determined by market** →

<table>
<tr><th>Market Design Elements</th><th colspan="4">Market Design Options</th></tr>
<tr><td>1
Low Carbon Central Planning</td><td>Bespoke arrangements
Technology-specific support, reflecting different stages of maturity and cost structures of each technology.</td><td>Inter low carbon tech competition
Market-wide regime for any low carbon technologies which have become ‘cost competitive’, and tech-specific support retained where competition is not possible.</td><td rowspan="2">Broad investment mechanism
Single mechanism supporting investment in low carbon technologies alongside all other technologies. It could be centralised, For example, an equivalent firm power auction with centralised procurement, or decentralised, for example a Supplier Obligation with multiple counterparties. The Broad Investment Mechanism would cover both support for low carbon technologies and investment for capacity adequacy.</td><td></td></tr>
<tr><td>2
Capacity Adequacy</td><td>Bespoke arrangements
Technology-specific support, reflecting different stages of maturity and cost structures of each technology.</td><td>Traditional Capacity Market
Solution could be similar to the current Capacity Market or an alternative means of competitively procuring firm capacity.</td><td>Wholesale price signals only
No capacity-based payments: firm capacity earns returns from peak wholesale power prices.</td></tr>
<tr><td>3
Flexibility</td><td>Bespoke arrangements
Technology-specific support, reflecting different stages of maturity and cost structures of each flexibility technology.</td><td>Long term flexibility contracts
A central body procures flexibility requirements under long-term contracts.</td><td>Joint procurement with firm capacity
A capacity adequacy market is adapted to include flexibility submarkets, for example by having minimum volumes of firm capacity that could also meet other technical flexibility criteria.</td><td>Short-term market revenue stacking only
Flexibility investments are solely supported by revenue stacking of wholesale revenues from peak prices and arbitrage, Balancing Mechanism revenues and short-term ancillary service market contracts.</td></tr>
</table>

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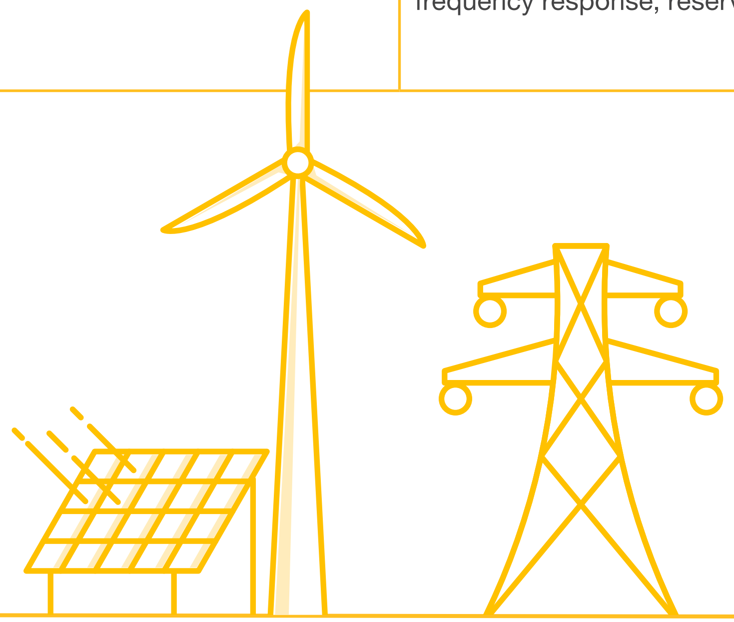
Operation Market Design Elements

Market Design Elements	Market Design Options		
	National wholesale market (with locational network charges)	**Zonal wholesale market**	**Nodal wholesale market**
4 **Location**	Similar to current arrangements but subject to potential changes to the network charging methodology.	The locational element would be largely removed from network charges, and a small number of wholesale markets (e.g. <6) would be defined.	The formation of a local market clearing price at different nodes in the electrical system. The price calculated at each node reflects the cost of energy as well as the cost of energy losses and congestion incurred in delivery.
	Bilateral self-dispatch		**Central dispatch and co-optimisation**
5 **Dispatch**	Generators and buyers contract bilaterally for the sale of electricity, specifying the time of delivery, volume of electricity to be traded and price. Generators decide when to dispatch, and the System Operator manages any imbalances.		Generation and consumption schedules and the dispatch of generation and demand is determined by the System Operator through an integrated scheduling process. Procurement of frequency response, reserve and energy is run jointly.



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Summary of Market Design Options Under Consideration

The table below summarises the different market design options under consideration for each element:

		First Order Elements			
Investment	1 Low Carbon Central Planning	Bespoke arrangements	Inter low carbon tech competition	Broad investment mechanism	
	2 Capacity Adequacy	Bespoke arrangements	Traditional Capacity Market	Broad investment mechanism	Wholesale price signals only
	3 Flexibility	Short-term market revenue stacking only	Bespoke arrangements	Long-term flexibility contracts	Joint procurement with firm capacity
Operation	4 Location	National wholesale market (with locational network charges)	Zonal wholesale market	Nodal wholesale market	
	5 Dispatch	Bilateral self dispatch	Bilateral self dispatch	Central dispatch and co-optimisation	

Indicates primary status quo arrangements

Second Order Elements

6 Low Carbon Support Mechanism

7 Settlement Period Duration

8 Ancillary Service Market Design

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Phase 2 Preliminary Assessment Results

We assessed the different market design options for each element against our 9 criteria. The criteria have not been given explicit weighting and have been considered independently. The order does not indicate relative importance. The options proposed for each element were given a relative scoring of Positive, Neutral or Negative. These scores are subject to review pending a more detailed assessment in Phase 3.

	Low Carbon Central Planning			Capacity Adequacy				Flexibility				Location			Dispatch	
Criteria \ Design Option	Bespoke arrangements	Inter low carbon tech competition	Broad investment mechanism	Bespoke arrangements	Traditional Capacity Market	Broad investment mechanism	Wholesale price signals only	Short term market revenue stacking only	Bespoke arrangements	Long term flexibility contracts	Joint procurement with firm capacity	National Wholesale Market	Zonal Wholesale Market	Nodal Wholesale Market	Bilateral self-dispatch	Central dispatch
Decarbonisation	Positive	Positive	Positive	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation
Security of Supply	No clear differentiation	No clear differentiation	No clear differentiation	Positive	Positive	Positive	Negative	Neutral	Positive	Positive	Positive	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation
Value for Money	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Positive
Competition	Neutral	Positive	Positive	Negative	Neutral	Positive	Positive	Negative	Neutral	Positive	Negative	Positive	Neutral	Neutral	Positive	Positive
Investor Confidence	Positive	Neutral	Neutral	Positive	Positive	Neutral	Negative	Negative	Neutral	Neutral	Positive	Neutral	Neutral	Negative	Positive	Positive
Consumer Fairness	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	No clear differentiation	Positive	Positive	Neutral	Positive	Positive
Deliverability	Positive	Neutral	Negative	Positive	Positive	Negative	Neutral	Positive	Positive	Negative	Positive	Positive	Neutral	Negative	Positive	Negative
Adaptability	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Positive	Positive	Neutral	Neutral	Neutral	Positive	Positive	Positive	Positive	Positive
Whole System	No clear differentiation	No clear differentiation	No clear differentiation	Positive	Positive	Positive	Neutral	Neutral	Positive	Positive	Positive	Neutral	Neutral	Positive	No clear differentiation	No clear differentiation

This summarises the relative strengths and weaknesses of each reform option. The detailed assessment is provided in the Appendix.

Positive | Neutral | Negative | No clear differentiation

Summary of options taken forward to Phase 3

We have ruled out two options for further consideration in Phase 3 because they did not score highly enough in our preliminary assessment.

		First Order Elements			
Investment	1 Low Carbon Central Planning →	Bespoke arrangements	Inter low carbon tech competition	Broad investment mechanism	
	2 Capacity Adequacy →	Bespoke arrangements	Traditional Capacity Market		Wholesale price signals only (b)
	3 Flexibility →	Short-term market revenue stacking only (a)	Bespoke arrangements	Long-term flexibility contracts	Joint procurement with firm capacity
Operation	4 Location →	National wholesale market (with locational network signals)	Zonal wholesale market	Nodal wholesale market	
	5 Dispatch →	Bilateral self dispatch		Central dispatch and co-optimisation	

Indicates status quo arrangements (shaded cream)

Indicates option ruled out for further consideration (shaded grey)

b

a

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Market Design Packages

Due to weaker interactions between the market design elements in the Investment category and those in the Operation category, the options for Investment and Operation have been assessed independently in Phase 2.

Our framework recognises that not all market design options can be practically combined.

Investment	'Bespoke arrangements' for low carbon support are currently combined with a traditional Capacity Market; however, as we move to a system dominated by a broader range of low carbon technologies (including CCS, BECCS etc), the capacity purchased through bespoke low carbon contracts may also provide the majority of the firm capacity requirement. Therefore, the case for a separate capacity auction to procure the small remainder of needs is less clear. Government is more likely to procure its low carbon contracts taking into account both its green and firm capacity requirements together. Technology-specific bespoke arrangements for capacity adequacy would not work well with the competitive procurement of flexible and firm capacity since there is some degree of overlap and the bespoke arrangements would distort and/or undermine the competitive process.
	Most low carbon and capacity adequacy options can combine with all flexibility options. The exception is that bespoke arrangements for the procurement of capacity adequacy cannot logically be combined with a competitive joint procurement of flexible and firm capacity.
Operation	Our framework postulates that the choice of Dispatch option automatically follows the choice of Location option. Based on international precedents, central dispatch would be a practical requirement if nodal pricing is adopted and would be most efficiently combined with co-optimisation of energy and reserve. Self-dispatch is therefore treated as incompatible with nodal pricing.

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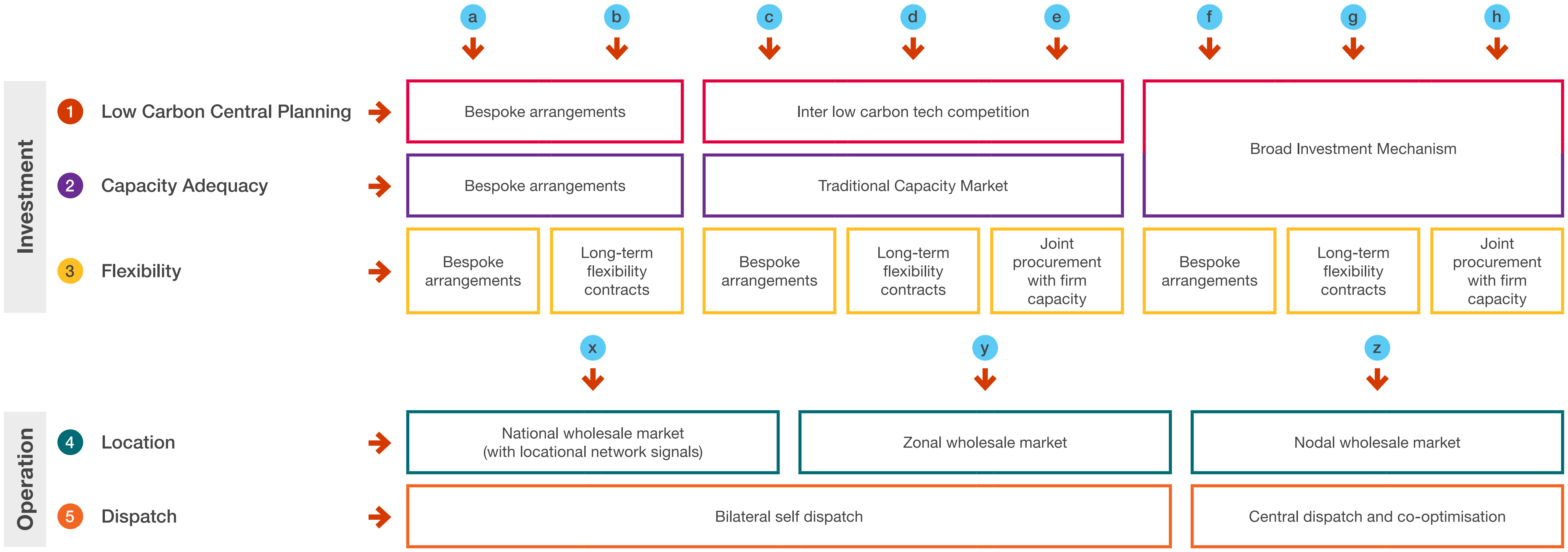
Phase 3 Options

Eight Investment packages (a-h) and three Operation packages (x-z) will be taken forward into Phase 3 to be assessed. Analysis of the Investment and Operation packages will be done in parallel.



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Next Steps

Phase 3 of the Net Zero Market Reform project will assess the first order priority investment and operation design options in depth, considering how different combinations of reforms can work in practice. We will also assess the three second order-priority elements: low carbon support mechanisms, settlement period duration and future ancillary service market design. Our assessment framework may evolve during the next phase, subject to ongoing consideration of how best to capture the interactions between market design elements.

As with Phase 2, we intend to combine our analytical research with extensive stakeholder engagement. We would be delighted to receive feedback on our work so far and look forward to gathering your input during Phase 3 of this project. We expect Phase 3 to conclude by April 2022 with a set of recommendations on market design and a roadmap for implementation.

You can register for updates on the Net Zero Market Reform project and find our contact details here. To learn more about parallel developments in the ESO Markets team please visit this webpage.

Net Zero Market Reform / Next Steps 38

Appendix

Modelling Methodology

Developing the Case for Change

1. Scenario modelling undertaken by LCP

LCP's modelling was based on ESO's three net zero compliant Future Energy Scenarios: Leading the Way, Consumer Transformation and System Transformation.

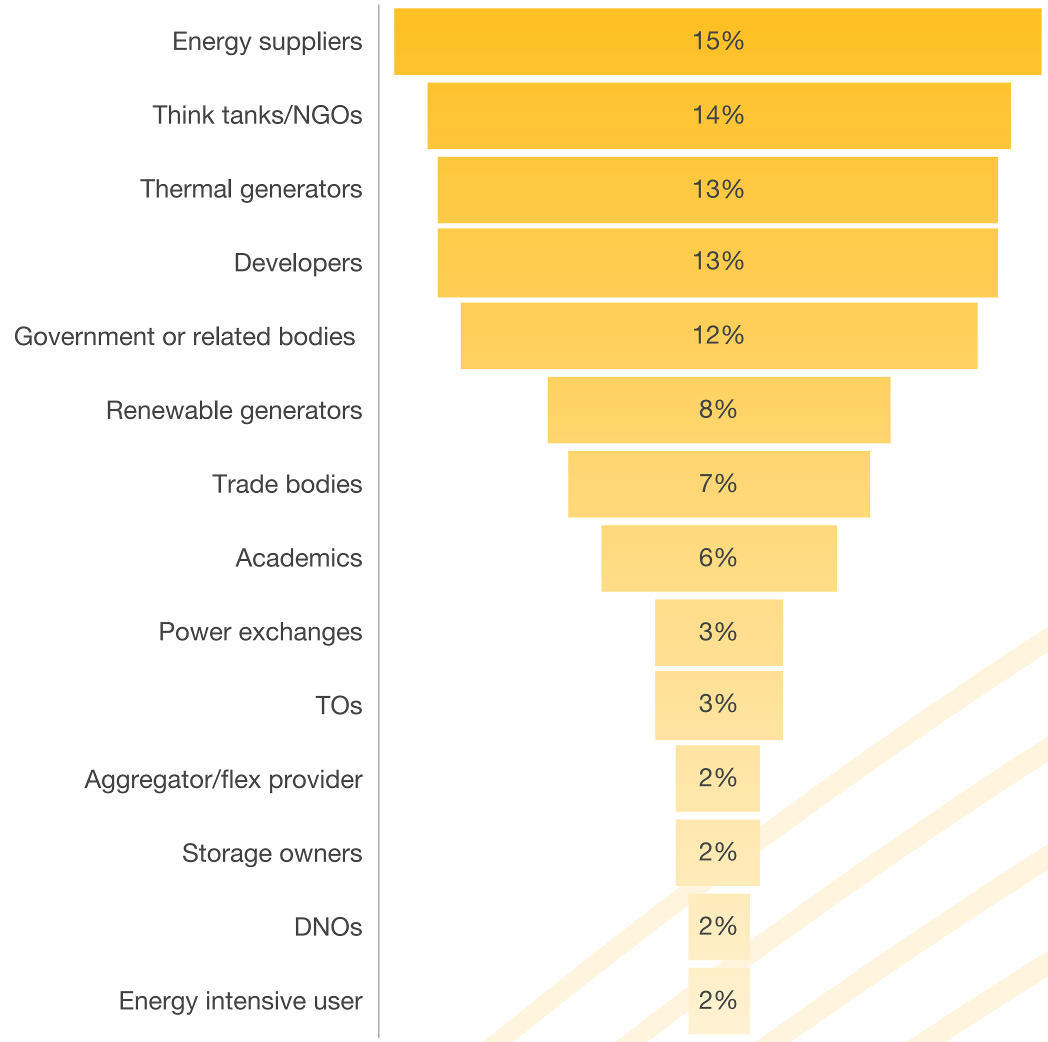
In the first part of the work, the analysis looked at the fundamental requirements of the future electricity system under each of the scenarios. Modelling five snapshot years (2025, 2030, 2035, 2040, 2050), the analysis identifies the different requirements for flexibility in dealing with a range of weather profiles and extreme events. Key outputs include the required level of firm capacity, the volumes of intraday, monthly and seasonal flex, levels of excess generation, implied load factors for the flexible fleet and system ramping requirements.

The second part of the work focused on projecting electricity market outcomes over the 2025-2050 period if the current market arrangements were to remain in place. The modelling simulates these market outcomes based on assumptions from the three scenarios (including capacity mix). Key outputs from this analysis include projections for each scenario of wholesale price, capture prices of different technologies, and balancing and capacity market outcomes. A further key output is the projected revenue split, for different technologies, between support mechanisms and market revenues (wholesale, balancing, capacity and ancillary) and how this may evolve over time and vary across scenarios.

The market modelling undertaken by LCP was based on a single GB unconstrained merit order and as such does not model redispatch due to locational constraints. The supporting evidence presented in this publication for the case for change on locational signals was derived from internal ESO analysis.

2. Feedback from external stakeholders

We ran a series of workshops with internal and external stakeholders to gather a range of perspectives on current and projected issues with electricity markets. Participants included asset owners, trade associations, energy suppliers and academics.



Net Zero Market Reform / Appendix 39

Market Design Options: results breakdown of preliminary assessment

Low Carbon Central Planning

Criteria \ Design Option	Bespoke arrangements	Inter low carbon tech competition	Broad investment mechanism
Decarbonisation	All options satisfy decarbonisation criteria	All options satisfy decarbonisation criteria	All options satisfy decarbonisation criteria
Security of Supply	Security of supply addressed separately	Security of supply addressed separately	Security of supply addressed separately
Value for Money	Lowest WACC and inframarginal rents but highest risk of inefficient technology choices	Lower WACC but higher risk of inefficient technology choices	Higher WACC but lower risk of inefficient technology choices
Competition	Competition limited between technologies	Greater competition between technologies	Full competition between technologies
Investor Confidence	Lower investor risks	More risks with the investor	Greater novelty and more risks with the investor
Consumer Fairness	Not clear this choice affects consumer fairness	Not clear this choice affects consumer fairness	Not clear this choice affects consumer fairness
Deliverability	No significant deliverability challenges	More complex auction arrangements required	Represents material change, so hard to deliver quickly
Adaptability	Long term contracts limit adaptability	Long term contracts limit adaptability	Long term contracts limit adaptability
Whole System	Technology specific support could allow for the targeting of non-electric technologies that may suffer from market failures, such as hydrogen. This could offer a whole system benefit if the H2 market is otherwise inefficiently small. However, if the H2 market is operating efficiently then artificially favouring H2 projects with electricity support would produce distortions and whole system disbenefits. There is no clear interaction with optimising across transmission and distribution systems.		

Positive Neutral Negative No clear differentiation

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Market Design Options: results breakdown of preliminary assessment

Capacity Adequacy

Criteria \ Design Option	Bespoke arrangements	Traditional Capacity Market	Broad investment mechanism	Wholesale price signals only
Decarbonisation	Not clear this choice affects decarbonisation which is directly addressed by the low carbon investment mechanism			
Security of Supply	Target capacity linked to reliability standard	Target capacity linked to reliability standard	Target capacity linked to reliability standard	Higher risk of insufficient capacity during some periods
Value for Money	Lowest WACC and inframarginal rents but higher risk of inefficient technology choices	Lower WACC and inframarginal rents but higher risk of inefficient technology choices	Higher WACC and inframarginal rents but lower risk of inefficient technology choices	Higher investor WACC but no inefficient technology choices
Competition	No competition between technologies	Competition between non low carbon technologies	Improved competition for technologies that can provide green and firm power	Competition between all technologies
Investor Confidence	Low risks with the investor and stable long term price signals secure investment in target projects	Some risks with the investor but stable long term price signals secure investment	Some risks with the investor but stable long term price signals secure investment, though new risks from novel regime	Full exposure of investors to market and policy risk
Consumer Fairness	Not clear this choice affects consumer fairness			
Deliverability	Likely to be able to be adapted from current arrangements	In line with the current system	Represents material change, so hard to deliver quickly	Gradual change due to current long-term contracts
Adaptability	Arrangements can be adapted in response to new developments	Arrangements can be adapted in response to new developments	Arrangements can be adapted in response to new developments	Dynamic response to changes in technology costs
Whole System	Security of electricity supply can support decarbonisation of other sectors via electrification. Current Capacity Market arrangements allow for transmission and distribution connected assets to participate equally. Likely that all of these arrangements could also accommodate the equal participation of transmission and distribution assets.			Security of supply risk may undermine decarbonisation of other sectors via electrification

Positive Neutral Negative No clear differentiation

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Market Design Options: results breakdown of preliminary assessment

Flexibility

Criteria \ Design Option	Short term market revenue stacking only	Bespoke arrangements	Long term flexibility contracts	Joint procurement with firm capacity
Decarbonisation	Not directly affected, but if less flex then possibly more RES curtailment			
Security of Supply	Firm capacity addressed separately but unclear if there will be sufficient technologies to address ramp rate requirements	Targeted capacity linked to operability and reliability standards	Targeted capacity linked to operability and reliability standards	Targeted capacity linked to operability and reliability standards
Value for Money	Higher WACC, but lower risk of over procuring flex	Lower investor WACC but risk of over procurement	Lower investor WACC but risk of over procurement	Lower investor WACC but risk of over procurement
Competition	Competition likely to favour technologies that primarily provide firm capacity and only some flex	Order of firm capacity and flexibility auctions could create unlevel playing field and tech bias	Joined up procurement of firm capacity and flexibility can provide more of a level playing field	Very limited competition between technologies delivering flexibility and limit to demand participation
Investor Confidence	Limited bankable revenues associated with flexibility	Some risks with the investor but access to some bankable revenues	Some risks with the investor but access to some bankable revenues. Also greater novelty in approach	Low risks with the investor
Consumer Fairness	Not clear this choice affects consumer fairness			
Deliverability	Similar to the status quo	Relatively limited change from status quo	More complex auction arrangements required, increasing if in broad investment mechanism	Likely to be manageable
Adaptability	Dynamic response to changes in technology costs	Arrangements can be adapted in response to new developments e.g. new technologies	Arrangements can be adapted in response to new developments e.g. new technologies	Arrangements can be adapted in response to new developments e.g. new technologies
Whole System	T&D optimisation possible. SofS risks may limit decarbonisation via electrification	T&D optimisation possible but depends on a consistent approach to D flex procurement**	T&D optimisation possible but depends on a consistent approach to D flex procurement**	T&D optimisation possible but requires ESO/ DSO coordination

Positive | Neutral | Negative | No clear differentiation

* Some of this assessment might change if bespoke arrangements are added alongside to address particular technology issues.
** Assessment assumes that the option does not mandate 100% of required flexibility to be procured long term and leaves some role for shorter term procurement as well.

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Market Design Options: results breakdown of preliminary assessment

Location

Criteria \ Design Option	National Wholesale Market	Zonal Wholesale Market	Nodal Wholesale Market
Decarbonisation	Decarbonisation is provided by the low carbon investment mechanism. The locational arrangements considered do not affect the achievability of this. Although they may affect the total cost of achieving decarbonisation, this is captured in the 'low cost' criteria.		
Security of Supply	Unclear how locational arrangements will affect security of supply		
Value for Money	Lack of transparent locational signals limits efficient investment	More transparent but less accurate locational signals*	More accurate and transparent but more volatile locational signals
Competition	National market supports competition	Likely some loss of wholesale competition	Likely greater loss of wholesale competition
Investor Confidence	More stable but lacking transparency	Potentially greater confidence for location based investments but this could be weakened if there is zonal instability. A novelty premium may also apply	Transparent but sensitive to small local investments. Novelty premium
Consumer Fairness	Status quo / moderate locational disparity in consumer costs	Reduced average disparity in consumer costs by location but potentially greater disparity by load profile	Likely to increase locational disparities in consumer costs
Deliverability	Similar to status quo	Significant reorganisation of the wholesale market. Impacts CfDs and transmission rights*	Very significant reform, implies adopting central dispatch which would also complicate other reforms
Adaptability	Charges can be updated on LRMC timelines	Market price signals automatically adapt to developments	Price signals automatically adapt to developments
Whole System	Similar to the status quo. May give rise to inconsistent T and D level locational signals	Likely to lead to inconsistency between T level and D level locational signals. (option defined as having no T level sub zonal signals)	Will provide coherent T&D locational signals down to nodal level

Positive | Neutral | Negative | No clear differentiation

* Experience from some markets in the US has shown that attempts to move to zonal prices can ultimately necessitate a move to nodal prices if there are significant within zone constraints. The current 27 generation zones for network charging suggests this may be a risk given that a zonal wholesale market would realistically only have around half a dozen zones.

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Market Design Options: results breakdown of preliminary assessment

Dispatch

Criteria \ Design Option	Bilateral self-dispatch	Central dispatch and co-optimisation
Decarbonisation	In principle, equally capable of supporting decarbonisation	
Security of Supply	In principle, equally capable of being consistent with security of supply	
Value for Money	Slightly less efficient wholesale price signals price signals for flexibility and reserve assuming that the ESO is a better forecaster than the market at the relevant time resolution and the central optimisation algorithm is reasonable.	Slightly improved price signal because constraint costs are reflected in the wholesale price assuming ESO better forecaster than market at the relevant time resolution and the central optimisation algorithm is reasonable.
Competition	Full bilateral traded markets provide good conditions for competition, provided that there is sufficient liquidity in the markets.	Historically in GB, central dispatch has been more susceptible to the exercise of market power. However, central dispatch is applied in many jurisdictions in the world and with sufficient plurality of market participants this issue should be able to be controlled.
Investor Confidence	Current bilateral trading arrangements provide investor confidence regarding wholesale markets. However, short term wholesale price signals reflect market participant expectations of ESO reserve requirements, rather than ESO's expectation. If the ESO is a better forecaster of reserve requirements in the relevant timeframe then bilateral trading will provide less transparent wholesale price signals for flexibility and reserve because more of the signal will go through the BM.	Likely to be some novelty premia in the GB context but investors will be familiar with this approach from other jurisdictions. Short term price signals will reflect ESO's expectations of reserve requirements. If this is more accurate in the relevant timeframe then this will provide more transparent wholesale price signals for flexibility and reserve.
Consumer Fairness	As today	No clear change relative to status quo
Deliverability	This is the status quo	Central dispatch would have major deliverability challenges and could complicate other possible reforms
Adaptability	Potentially more adaptable because contracting is less constrained	Potentially less adaptable as it relies more on central processes but this is unlikely to materially constrain he ability to adapt to relevant changes
Whole System	No clear interactions. Both self dispatch and central dispatch could support the decarbonisation of other energy vectors and the optimisation across transmission and distribution. To optimise under central dispatch the ESO will need to be aware of distribution constraints to optimise but this should not be a barrier.	

Positive | Neutral | Negative | No clear differentiation

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Glossary

Ancillary Services
Services procured by the ESO to support operation of the electricity system.

Baseload Generation
An electricity generator that tends to operate at constant output for 24 hours a day throughout the year.

Bioenergy with Carbon Capture and Storage (BECCS)
The coupling of bioenergy with carbon capture and storage to capture the CO2 produced during combustion. This process delivers negative emissions.

Capacity
The power output of an electricity generation technology usually measured in Watts (or kW, MW or GW).

Capacity Market
The Capacity Market is designed to ensure security of electricity supply. This is achieved by providing a payment for reliable sources of capacity, alongside their electricity revenues, ensuring they deliver energy when needed.

Contract for Difference
A contract between the Low Carbon Contracts Company (LCCC) and a low carbon electricity generator, designed to reduce its exposure to volatile wholesale prices.

Curtailment (Grid Curtailment)
This is when the output from a generation unit connected to the electricity system is reduced due to operational balancing.

Demand Side Flexibility
The ability of energy users to adjust demand in response to market signals.

Electrolysis
Electrolysis is the process of using electricity to split water into hydrogen and oxygen.

Excess Demand
For the LCP analysis, this is defined as electricity demand net of generation from intermittent renewables, baseload low carbon generation (nuclear and BECCS) and assumed interconnector flows.

Excess Generation
For the LCP analysis, this is defined as electricity generation from intermittent renewables, baseload low carbon generation (nuclear and BECCS) and assumed interconnector flows, net of electricity demand.

Flexibility
The ability to adjust either the supply or demand of electricity.

First of a Kind (FOAK)
Refers to the first item or generation of items to use a new technology or design, when the cost tends to be substantially higher than later generations.

Interconnectors
Transmission assets that connect the GB market to markets in other countries and allow market participants to trade electricity between these markets.

Intermittent Generation
Types of generation that can only produce electricity when their primary energy source is available. For example, wind turbines can only generate when the wind is blowing.

Load Factor
Load factors are a measure of how active a generation plant or technology type is across a year, expressed as a percentage. It is calculated by dividing the total electricity output across the year by the maximum possible generation.

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Loss of Load Expectation (LOLE)

Used to describe electricity security of supply. It is an approach based on probability and is measured in hours/year. It measures the risk, across the whole of winter, of demand exceeding supply under normal operation. This does not mean there will be loss of supply for 3 hours per year. It gives an indication of the amount of time, across the whole winter, which the Electricity System Operator (ESO) will need to call on balancing tools such as voltage reduction, maximum generation or emergency assistance from interconnectors. In most cases, loss of load would be managed without significant impact on end consumers.

Net Zero

When the total amount of greenhouse gases emitted in a year reaches zero, after all emissions and all carbon sequestration has been accounted for. This is the current UK target for 2050.

Peak Demand, Electricity

The maximum electricity demand in any one fiscal year. Peak demand typically occurs at around 5:30pm on a week-day between November and February. Different definitions of peak demand are used for different purposes. FES uses the Average Cold Spell (ACS) definition which is consistent with the treatment of demand in the electricity Capacity Market.

Time of Use Tariff

A charging system that is established in order to incentivise consumers to alter their consumption behaviour, usually away from high electricity demand times.

Weighted Average Cost of Capital (WACC)

The weighted average of the cost of equity and the cost of debt, where the weighting is provided by the gearing ratio.

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nationalgridESO