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Future Energy Scenarios: Pathways to Net Zero

2025 Methodology document

NESO
National Energy System Operator

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1. Introduction

This document sets out the purpose of Future Energy Scenarios (FES), considering how we assess and develop credible routes to net zero through extensive analysis, research and stakeholder engagement. It also outlines the key principles in our whole system modelling approach and our processes concerning data transparency, governance and stakeholder engagement.

This document does not examine how our models work or our assumptions and data inputs. These are explored separately in the *FES Modelling Methods* and *FES Pathway Assumptions*, which are published on our website and updated during each FES cycle.

The document was produced before the final Ofgem Guidance Document was finalised and is, therefore, based on our latest understanding of requirements.

2. About Future Energy Scenarios

FES is published by the National Energy System Operator (NESO). It explores strategic ways in which energy demand, supply and flexibility can develop out to 2050 to achieve Great Britain's net zero targets.

FES considers the development of low carbon technologies, exploring the impact on energy demand and supply alongside the role of flexibility and consumer engagement. Our analysis is underpinned by an extensive programme of stakeholder engagement, incorporated in our outputs alongside our own analysis and research. This is published in a suite of documents on the NESO website. We also produce a *Ten-Year Forecast* (10YF) as part of the FES cycle to feed into gas security of supply planning.

Our analysis is used across downstream processes to inform network investment, operability, markets, Security of Supply (SoS) planning and the energy industry. It also informs the *Electricity Ten Year Statement* (EYTS), *Gas Ten Year Statement* (GTYS) and *Network Options Assessment* (NOA), and has supported operability frameworks and market analyses such as the *Review of Electricity Market Arrangements* (REMA). FES continues to play a crucial role in ensuring SoS through the electricity Capacity Market (CM) and both the *Summer Outlook* and *Winter Outlook*, as well as supporting investment in low carbon demand and supply technologies, academic research and policy development.

FES is not intended to forecast or predict what will happen. It is, instead, our responsibility to present a series of credible strategic routes to net zero and legally binding interim emissions targets.

FES will input directly into several strategic energy plans that identifies and drives the network investment required to achieve carbon budgets and net zero targets. Our interactions with NESO's strategic energy planning (SEP) processes are outlined in more detail in section 2.1 of this report.

FES is used for a number of regulated activities and is referenced by a wide range of industry stakeholders. Since the establishment of NESO in October 2024, it has with NESO's new responsibilities. This business-wide strategic shift is reflected in our updated framework, the cadence at which we will publish FES in the future, alongside the extension of the 5YF this year, transitioning to the 10YF.

2.1 Future Energy Scenarios within NESO's strategic energy planning processes

Previous FES frameworks presented a wide range of credible outcomes of how Great Britain could achieve net zero. In 2024, our framework shifted to explore a narrower range by identifying strategic choices that can be made on the route to net zero. This evolution forms part of a wider industry overhaul to Great Britain's energy network planning, with FES underpinning the foundations of this network investment by working alongside the *Strategic Spatial Energy Plan* (SSEP) and feeding into the *Centralised Strategic Network Plan* (CSNP).

The SSEP will set out a long-term view of what energy sources are needed to reach net zero and their most optimal locations across Great Britain on a zonal basis from 2030 to 2050. To read more about their approach in detail, please refer to NESO's Strategic Spatial Energy Plan draft methodology document.

Following this spatial blueprint, the CSNP will then recommend the best options to connect power to regions and the optimal sources to provide it. The CSNP is a whole system network plan, considering high-level transmission investments against a range of design objectives, encompassing our current electricity network planning outputs.

NESO is working with Distribution Network Operators (DNOs), local councils, energy providers and communities to develop 'bottom-up' plans to help forecast future energy needs (at a regional level in England and national level in Scotland and Wales), based on each area's vision for industry, homes and transport. This information will form part of the Regional Energy System Planner role of NESO.

In line with Ofgem guidance, and to align with the upcoming SSEP and the CSNP, FES will move to a three-yearly cycle for major updates. Annual 'minor' FES updates may be published within this period if we deem a significant change to have occurred during the cycle.

2.2 Stakeholder engagement

Stakeholder engagement is fundamental to developing our pathways and the Counterfactual. It underpins our modelling, analysis, insights and recommendations, as well as helping improve the accessibility and design of the main report and suite of documents.

We engage with stakeholders in several ways, including online consultations, in-person events and bilateral meetings to help ensure we reach a wide range of stakeholders. Additionally, we work closely with colleagues across NESO to coordinate wider stakeholder engagement activities across the organisation and share feedback.

We continually review our stakeholder numbers and categories to ensure we seek the best possible mix of views from across the energy sector.

Figure 1: FES 2025 stakeholder engagement timeline

Online consultation

We issue an online consultation at the beginning of each FES engagement cycle. This seeks feedback on all aspects of the publication, including inputs, outputs, assumptions and data, as well as the structure and format of the publication. Areas of focus for the consultation are developed by our analytical and stakeholder teams to explore any potential areas of improvement.

Bilateral meetings

Bilateral meetings are held to gather information and feedback to seek additional expertise. These take place on both a proactive and reactive basis.

In-person events

We hold round table events, such as our Topic Table Talks (TTT) events, to gather views from stakeholders, test assumptions, receive challenges to existing views and opinions, and explore new ideas for future FES publications. We also hold a range of events during the FES launch period to communicate key findings and receive immediate feedback and questions. Plans for the 2025 publication will be developed in the coming months and communicated to stakeholders.

Keeping in touch

We keep in touch with stakeholders throughout the year via NESO's email newsletter, website and social media accounts.

Feedback is welcomed year-round via our email address:
FES@nationalenergyso.com.

2.3 Future Energy Scenarios framework

The FES framework is designed to guide the analysis for credible pathways to deliver Great Britain's 2050 net zero and interim emissions targets, exploring areas of uncertainty and where key decisions will be needed.

Since 2020, our pathways (formerly scenarios) have been defined by two key metrics: these have changed from affordability and sustainability in 2014 to demand flexibility and decarbonised energy mix (hydrogen/electrification) in 2024. These levers reflect the contemporary challenges and ambitions of energy usage in Great Britain. The range in demand side flexibility demonstrates uncertainty and its value towards the whole energy system.

Our pathway narratives are developed around a framework to explore routes to net zero and provide the foundations of our analysis and the main report. FES 2024 was built on three net zero pathways: Holistic Transition, Electric Engagement and Hydrogen Evolution. Each one explored a strategic route to net zero based on extensive stakeholder engagement, research and analysis. A Counterfactual was also presented which explored a world where progress in decarbonisation is slow against current policy and emissions targets are not met.

We publish outputs of our analysis in the following areas:

- Energy demand
- Electricity supply
- Hydrogen, gas and bioenergy supply
- Demand and supply side flexibility
- Whole economy emissions.

For sectors that fall outside our modelling, we will use the Climate Change Committee's (CCC) Seventh Carbon Budget analysis (due to be published in February 2025).

Since the publication of FES 2024, we have also undertaken analysis on achieving clean power which informed *Clean Power 2030* advice. The framework for this analysis focused on supply side technologies looking at renewables-based systems and new low carbon dispatchable power.

Stakeholder feedback was positive, both on the changes to the FES 2024 framework and that used to develop our *Clean Power 2030* advice. We are, therefore, looking to bring key elements of each framework together for FES 2025. This means considering the three demand pathways with the range of uncertainty around fuel switching and consumer engagement (as in our 2024 pathway analysis) while considering the dispatchable and weather dependent technology on the electricity and hydrogen supply sides.

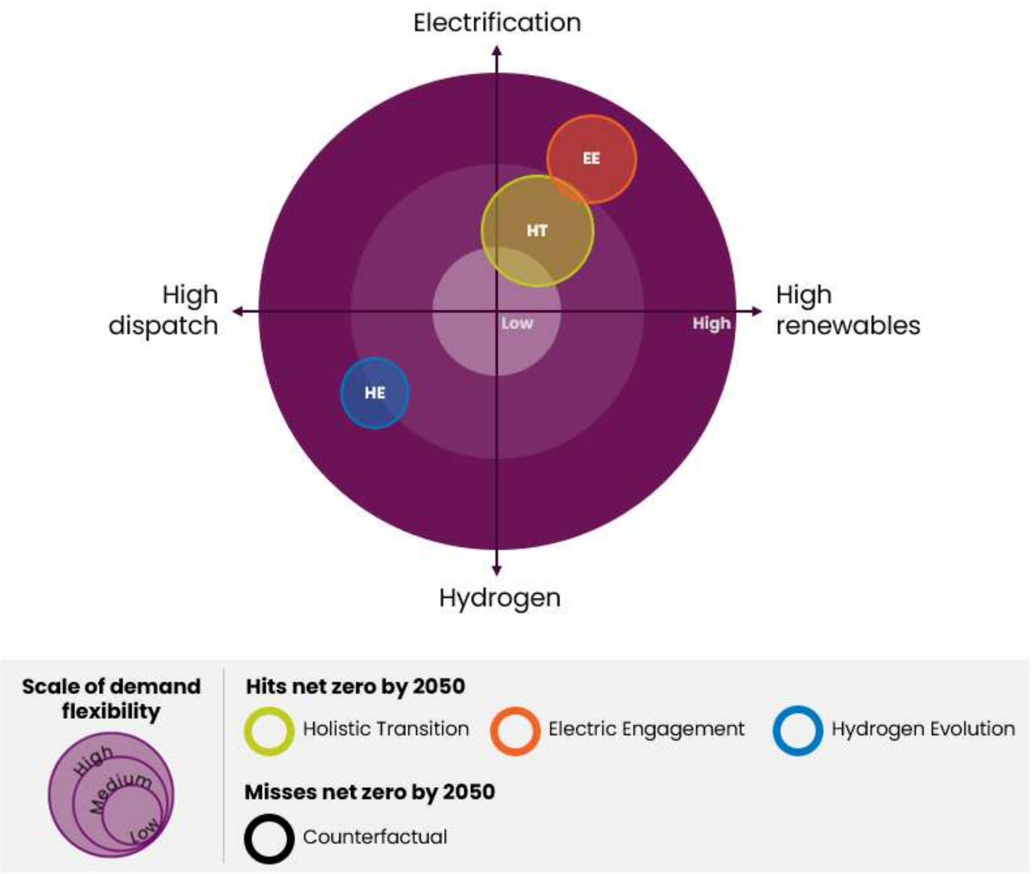

Figure 2: FES 2025 draft framework graphic

Our pathway framework graphic, names and positions are still under development and will be confirmed prior to publication of our analysis. Pathway positions are indicative and subject to change through analytical governance processes.

2.4 Net zero pathways explained

FES 2025 will explore three supply and demand pathways that meet net zero and interim emissions targets. Pathways are designed to help accelerate the development of the energy network by focusing on outcomes that achieve net zero.

Our pathways consider all energy vectors, and our methodology seeks to outline a robust, whole system approach that evolves over time as our modelling capabilities grow, data becomes available and new technologies develop.

Each pathway will be shaped by a set of overarching assumptions that form the pathway narrative and starts by considering what is likely to happen in the short term. The pathways then explore credible decarbonisation routes that align with each (for example, high consumer engagement or high hydrogen demand) and evolve through continuous stakeholder engagement and research.

FES pathways are intended to be specific about the type, timing and scale of investment needed, rather than illustrate how possible changes in consumer or generation developments could lead to reaching net zero. These specifics will help us determine if a policy target or ambition is feasible and can be met.

The pathways will extend out to 2050, the date by which the legally binding net zero target applies and as required by the CSNP. Alongside this, our pathways will meet the legally binding carbon budgets set by the CCC and Nationally Determined Contributions (NDCs).

2.5 The Counterfactual

The Counterfactual explores the credible slowest rate of decarbonisation. Although some progress is made in decarbonisation compared to today, uptake of low carbon technology is slow and means that emissions targets are not achieved.

2.6 National and regional outputs

The pathways are intended to illustrate credible demand and supply outcomes from now to 2050 at a Great Britain level. To support further analysis downstream, the pathways are broken down into regional datasets.

Demand

For our demand analysis, this includes a view of gross (underlying) and net (transmission) demand for each pathway out to 2050. Each year includes three study periods: winter peak, summer minimum AM and summer minimum PM. The electricity demand data is provided for each grid supply point (GSP) (a connection between the transmission and distribution network) and demand direct connect (a connection between the transmission network and a large energy user). Gas demand is split by Local Distribution Zone as required to feed into the gas demand statements. Hydrogen demand is distributed to suit the hydrogen availability in the pathways.

Electricity supply

The embedded and sub 1 MW generation forecasts are apportioned according to the existing geographical distribution for all technologies (wind, hydro, storage and other distributed generation technologies). The exception to this is solar; as solar installed capacity increases, we assume a more widespread regional distribution across the country. For storage, the existing capacity and new sites with a known location are allocated to a GSP using a project-based approach.

Future growth that does not yet have a known location is split at GSP level based upon the year-by-year increase in all distributed generation technologies spatially. The current and forecasted embedded generation capacities for each GSP are provided along with peak winter and summer forecasts.

Natural gas supply

Supply pathways are modelled by considering several available supply sources, their historic outputs and future projects of their gas production. These supply sources include the UK Continental Shelf (UKCS), Norway, European imports, liquefied natural gas (LNG), biomethane and other generic imports.

Hydrogen supply

This is modelled by a two-stage approach. A hydrogen asset database containing all known hydrogen projects in development is used to assess the period to 2031, with a likelihood assigned to projects and whether they go ahead. An optimised capacity expansion model (CEM) is used for the period 2031-2050, taking into account future hydrogen demand, production technology options (such as electrolysis, gas reforming), storage needs and regional considerations. To improve our whole system approach to modelling, the hydrogen CEM will, this year, be incorporated into the electricity CEM (known as the Co-optimised CEM).

Biomass for bioenergy supply

Figures are taken from the most recent carbon budget report from the CCC and applied as a national-level envelope for all bioenergy users (for example, bioenergy with carbon capture and storage (CCS)).

Regional pathways

NESO has taken on the role of RESP, a new body established to ensure energy networks are regionally coordinated across fuel vectors and between geographies, with the right level of local input into the process as well as regional democratic oversight. As part of this role, NESO will be producing regional pathways for a transitional RESP report to be published in 2026. FES 2025 will form part of the inputs into the transitional RESP and we are working towards alignment approaches and interactions between the FES and RESP processes. An enduring methodology for RESP pathways is also being developed, considering both the FES and SEP methodologies. This will be used to produce the RESP pathways.

As such, FES 2025 will not include regional pathways, but we will continue to provide data broken down regionally in our data workbook alongside additional guidance on how this is split.

2.7 Stakeholder feedback on our pathways

We asked stakeholders for views on introducing a single short-term pathway.

Opinion was split on this. Those in favour felt that it could add more short-term certainty and increase confidence in growth-driven investment decisions. Additionally, it could, some felt, help support an accelerated pace of network reinforcements and enable more granular visibility of assumptions. Some suggested capturing any flexibility and adaptability through sensitivity studies, which could explore the different possible paces towards net zero as well as technologies with less short-term certainty.

It was, however, noted by some that uncertainty could make the development of optioneering and sensitivity analysis more difficult. In addition, while a single short-term pathway could help develop regionally reflective pathways across RESP areas, some pointed out that, with FES 2025 the final publication before moving to a three-yearly cycle, this could lead to differences at a geographic level which would then extend out to 2028.

Those in favour of maintaining multiple pathways felt that a single pathway could lock us into a trajectory which would then fail to explore credible routes if 2030 targets are not met. They noted that strategic decisions still to be made across some sectors (such as hydrogen for heat) and a single pathway would not capture this. Some also pointed out that the current pathways are used for a range of purposes (such as capacity adequacy planning) where a range is beneficial. Some stakeholders also highlighted that a single pathway could not capture potential lack of adoption of widespread residential energy efficiency, demand flexibility or demand turn-up. Nor could a single pathway capture emerging technologies.

NESO's response

We acknowledge the different points made by stakeholders, both in favour of a single pathway and maintaining multiple pathways. Our view is that the current policy environment does not yet provide enough certainty to move to a single pathway. We will continue to explore uncertainty through multiple pathways for FES 2025.

We expect our FES 2025 pathways will be narrower to 2030 with an additional year of history and following the analysis completed for the Clean Power 2030 advice. We will consider how the uncertainty and pathways are presented throughout our analysis and provide an update prior to the publication of FES 2025.

We asked stakeholders for views on when the pathways should branch out to cover wider uncertainty.

Most stakeholders recommended that 2030 should ensure consideration of the Clean Power 2030 advice and subsequent government plan. It would also allow for the impact of connections reform, publication of SSEP and RESP pathways and potential market reform. Additionally, this would allow time for development of no or low regret options and sufficient data collection and analysis to inform more detailed and diverse future long-term pathways. Some added that any short-term pathways should span eight years which would fit with the current price control period of five years and the typical development period of three years prior to commencement of the price control period. A shorter pathway period may mean missing the advantages of coordinating cross-vector investment within network company business plans.

NESO's response

For FES 2025, our pathways will continue to represent the range of uncertainty and will diverge from today. However, to meet near-term emissions targets, the pathways will remain narrow up to 2030.

We asked stakeholders for their views on the focus of the narratives in the pathways.

The pathway framework for FES 24 received very positive feedback with the consideration of fuel switching and demand side flexibility. Some stakeholders wanted to see the pathways aligned with those in the *Clean Power 2030* advice to Government, incorporating a supply side angle. Other suggestions included speed of transition, electrification alongside hydrogen, hydrogen alongside gas CCS dispatchable power and whole system thinking.

Stakeholders also suggested considering behavioural, technology uncertainty and policy changes, exploring constraints around the scale of roll-out of different technologies. It was suggested that at least one of the net zero pathways does not rely too heavily on highly optimistic assumptions about new technologies. Some wanted to see pathways built from the bottom up and based on observable, tangible data (particularly in relation to consumer behaviours and sentiment) so that all pathways are informed by indicators from what we see today.

It was also suggested that the economic modelling (introduced in FES 2024) should be developed further, placing a greater focus on system cost optimisation that reflects the spectrum of technology cost uncertainties. We intend to include additional economic analysis and insight from our pathways and will provide additional details of the scope prior to publication.

NESO's response

Based on stakeholder engagement the narrative/framework designed for FES Pathways 2024 has been well received. We aim to bring in learnings from our Clean Power 2030 advice on the supply side, updated to reflect a whole system view.

We asked stakeholders for views on the triggering criteria that should be met before we introduce a single pathway.

Criteria suggested by stakeholders included considerations around connection and market reforms, significant policy changes (for instance, hydrogen for heat or European policy alignments) and implementation of the Clean Power 2030 plan.

Other factors included technological breakthroughs, behavioural changes and exposure to European power and gas markets.

NESO's response

We agree with the suggested triggering. We will continue to consider a single pathway and the triggering criteria for this for later FES publications.

We asked stakeholders how they have used the Counterfactual and their views on how we could present it.

Stakeholders broadly felt the Counterfactual provides a useful means of showing what happens if we lack progress, representing a realistic and pragmatic approach and helping highlight economic impacts and implications of delays.

Suggestions included adding some narrative to the Counterfactual around continued exposure of the UK to imported fossil fuels. Some also advised that, as it is used as a sensitivity in network planning, it should represent the upper and lower bounds with which networks would be prepared to cope. However, some stakeholders did caution that, without insight on system costs, it adds less value. The addition of cost data and other metrics around social impact would, some felt, significantly enhance it.

Stakeholders suggested that it should be made clear that there is no world in which a continuation of the Counterfactual's status quo is likely. Similarly, some felt that other ways to describe The Counterfactual as a non-delivery scenario would be welcome; this could then, over time, be captured by developing more than one non-delivery scenario subject to progress towards 2050 net zero target and any prevailing major uncertainties.

NESO's response

We will continue to present a Counterfactual alongside our pathway analysis. Our Counterfactual will continue to consider a world where some, but minimal, progress is made towards decarbonisation and it misses net zero. We intend to bring in additional analysis and insight on system cost and will provide additional details of scope prior to publication.

We asked stakeholders for views on what criteria should be triggering a major update outside a three-year cycle.

Stakeholders had a range of opinions on this. Policy and markets were one area, including, for instance, decisions on hydrogen for home heating and nuclear, major updates to policies or targets (including technology-specific targets) or major structural market impact or planning reforms. Some added that change in UK political conditions (a new national government, for example) or geopolitical events may also trigger a major update as could missed milestones on decarbonisation targets. The second area raised by stakeholders was cost – for instance, any significant change in the cost of energy or infrastructure. Finally, stakeholders also discussed supply chain (notably, disruptions to supply chains) and technological breakthroughs.

NESO’s response

“We will continue to review the triggering criteria beyond FES 2025. We believe that some of the trigger points raised by stakeholders may warrant additional analysis and commentary but would not necessarily mean a full requirement for updated pathways when considered alongside the other work done as part of strategic network planning.

3. Our modelling and whole system approach

3.1 What we model

We directly model the following sectors out to 2050 on both the demand and supply sides including flexibility, in the FES process:

- Transport
- Heat
- Industrial and commercial
- Residential
- Power

Our inputs come from a variety of sources, including desk-based research, stakeholder engagement (bilateral meetings and in-person events), government datasets (such as DESNZ Energy Trends, Department for Transport), economic consultancies (for areas such as fuel prices, GVA per sector) and industry bodies (for areas such as heat pump rollout). In some cases, we make use of analysis carried out by other teams within NESO.

Forward looking modelling is inherently exposed to uncertainty. Our approaches to managing and communicating this uncertainty is described in section 4.1.

Greenhouse gas emissions from some sectors are not directly modelled in FES. Data is taken from the CCC's most recently published carbon budget. Emissions modelling of the following sectors are judged to fall outside NESO's whole energy remit and here we use the most recently published values from the CCC:

- Aviation (including international emissions)
- Marine (including international emissions)
- Waste
- Agriculture
- Land use, land-use change and forestry (LULUCF)
- Industrial process emissions
- Fluorinated gases
- Fuel supply related emissions.

3.2 The demand modelling process

Future projections for overall demand are created using forecasts and assumptions from other models used in FES such as:

- Industrial and commercial demand, including data centres

- Residential appliances, lighting, and air conditioning
- Heat and district heat
- Road and rail transport.

These components are combined to provide a view of consumer electricity demand. This is then supplemented with additional components including losses from the transmission or distribution of electricity, exports via interconnectors and the amount of consumer demand that can be altered in response to price signals or met through generation sources not connected to the transmission network. This area also includes the electricity needed to produce hydrogen or other non-consumer loads.

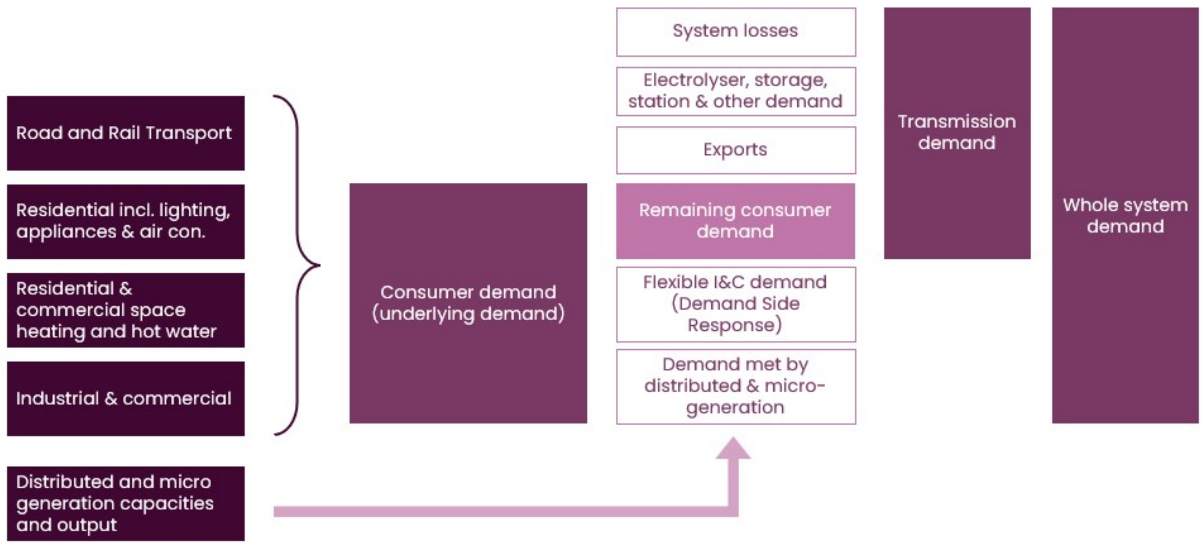

Figure 3: Overview of electricity demand components

These demands are further divided in the total electrical energy needed to meet all demand each year (annual demand) and the demand at the maxima/minima points in the year (the peak or minimum demand respectively). FES also models demand side response.

Each sector model looks across multiple fuels, including electricity, gas and hydrogen alongside efficiency improvements. To set the inputs to our sector models, we use a combination of research and stakeholder engagement, as well as applying the pathway framework (including ensuring that emissions targets are met) and making use of externally provided datasets. Once we have modelled the demand for each sector, we aggregate together the demand for each fuel (electricity, gas and hydrogen) and scale the consumption based on the latest set of observed demands.

The demand for each fuel is then handed across to the supply teams. There is then a feedback loop, where non-consumer demand (gas and hydrogen demand for power generation; gas and electricity demand for hydrogen production) are determined and added to the overall demand totals.

We have introduced additional focused stakeholder engagement activity for energy demand in FES 2025. This includes a dedicated demand focused event for our stakeholders to provide feedback and improvements on our FES 2024 analysis. We have also introduced challenge and review sessions with external stakeholders (including electricity and gas networks, Ofgem and Department for Energy Security and Net Zero (DESNZ)) on our input assumptions. This provides additional opportunity to comment on our inputs before we commence the modelling.

3.3 The energy supply modelling process

The supply sectors directly modelled within FES include electricity production, natural gas, hydrogen production and bioenergy supply. We will reflect our *Clean Power 2030* analysis in FES for 2030. We define short-term supply modelling as pre-2031 and long-term supply as beyond 2031.

Electricity supply

Our short-term electricity supply modelling is based on recent capacity auction results, market and project intelligence and data from the distribution and transmission-connected capacity registers. This is applicable to both generation and storage at all voltage levels, as well as interconnectors.

Over the long term (beyond 2031), to simulate generation and storage build out of electricity supply on the transmission level, we use PLEXOS energy modelling software, produced by Energy Exemplar[1]. This is a pan-European electricity model capable of simulating the electricity market in Great Britain and other countries. Distribution-connected electricity supply beyond 2031 is calculated separately using bottom-up assumptions.

PLEXOS CEM for electricity and hydrogen supply seeks the lowest total long-term cost for the mix of transmission-connected generation and storage which meets carbon budgets and net zero emissions reduction targets. We have added a reserve margin to CEM which ensures the firm capacity of all generation plants meets peak demand, plus 4% - this means we can ensure our generation capacity mix is applicable for multiple (and even more extreme) weather years.

Our dispatch (production) model is used to optimise all the input information, from the baseline year to 2050, provided with the objective of minimising the total system

[1] https://www.energyexemplar.com/plexos

cost, subject to constraints. The dispatch model contains information such as the existing and future assets (derived from CEM) considered in the pathways studies, techno-economic system parameters, demand profiles, various flexible demand archetypes, renewable weather profiles, market-related prices, operational constraints, among other things. Our dispatch model seeks to emulate, as far as possible, the outcome from real market-clearing engines.

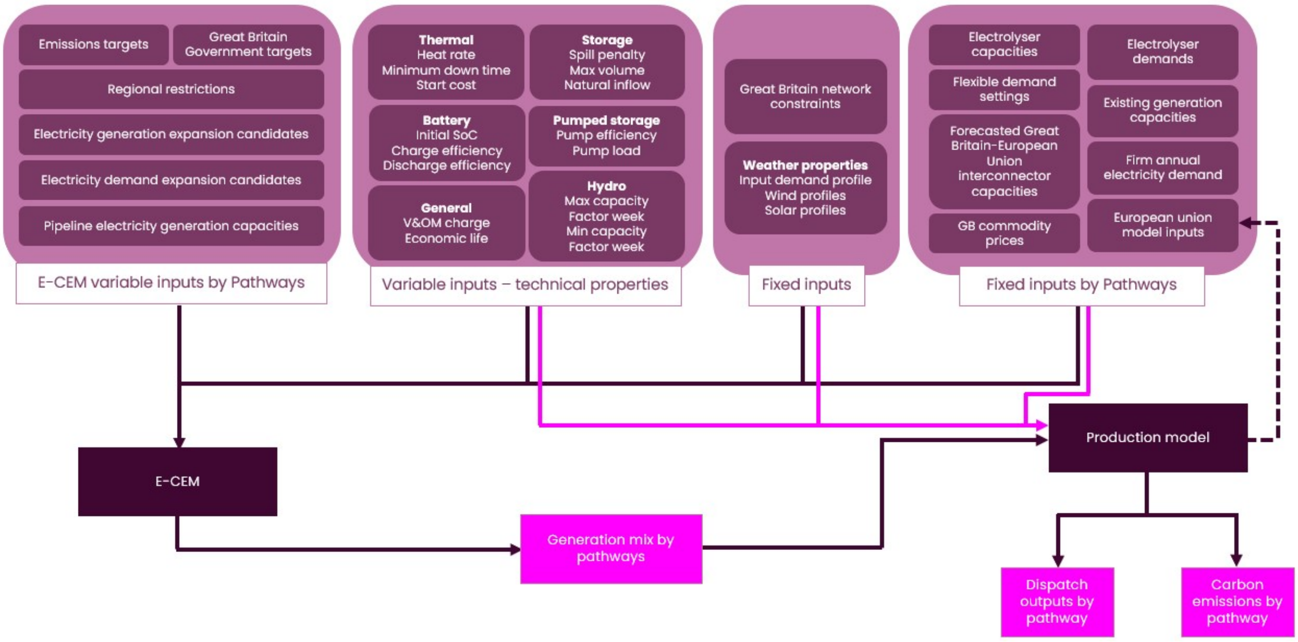

Figure 4: Electricity supply process

Hydrogen supply

Hydrogen supply is modelled via two approaches. In the near term to 2031, a database of projects is assessed against hydrogen demand to determine the most likely amounts of hydrogen supply to come online in each pathway. Beyond 2031, this is modelled via PLEXOS CEM, which is a technoeconomic model. This is in a co-optimised model for FES 2025 with the electricity supply modelling to produce the hydrogen supply mix to meet future demand. It includes a combination of hydrogen production build and storage build needed based on individual pathway levers and assumptions to produce these results.

Electricity and natural gas use required to produce this hydrogen is included in the demand that is used in modelling the supply of these energy vectors.

We reference the latest government updates, other industry databases, and conduct our own research using public materials, developer reports, and stakeholder input to determine the sources of known projects.

Gas supply

Natural gas supply modelling draws from a range of forward-looking forecasts of gas supply from the UKCS and Norwegian gas fields, alongside European gas, LNG and biomethane availability. These are then matched to the pathway and the Counterfactual demand for natural gas.

Bioenergy supply

Our bioenergy model is designed to integrate bioenergy demand across the whole system, ensuring a sustainable and balanced supply chain. It incorporates bioenergy demand from various sectors, including power generation, heating and transport, with demand derived from sector-specific models such as Plexos and the Spatial Heat Model. For sectors not directly modelled in the Pathways, such as the aviation sector, we will reference the CCC’s Seventh Carbon Budget.

The bioenergy supply accounts for various bio resource types (for example, wood pellets, energy crops or waste) to meet specific demand. The CCC’s Seventh Carbon Budget will serve as a benchmark to ensure the total bioenergy demand and supply remain within the sustainable limits outlined in the CCC's balanced pathway.

Additionally, the model also seeks to balance domestic bioenergy resources with imports across different pathways, using the import ranges outlined in the CCC’s Sixth Carbon Budget report as the benchmark. This ensures a comprehensive view of potential future sources of bioenergy.

Emissions modelling

Three of our pathways meet net zero by 2050. The Counterfactual represents the slowest credible rate of decarbonisation and does not reach net zero by 2050. There are other binding commitments (such as carbon budgets set by the CCC) which form part of our analysis.

Emissions modelling can be broadly broken down into two main areas: sectors modelled directly by the team and sectors where we use third party analysis, such as the CCC’s.

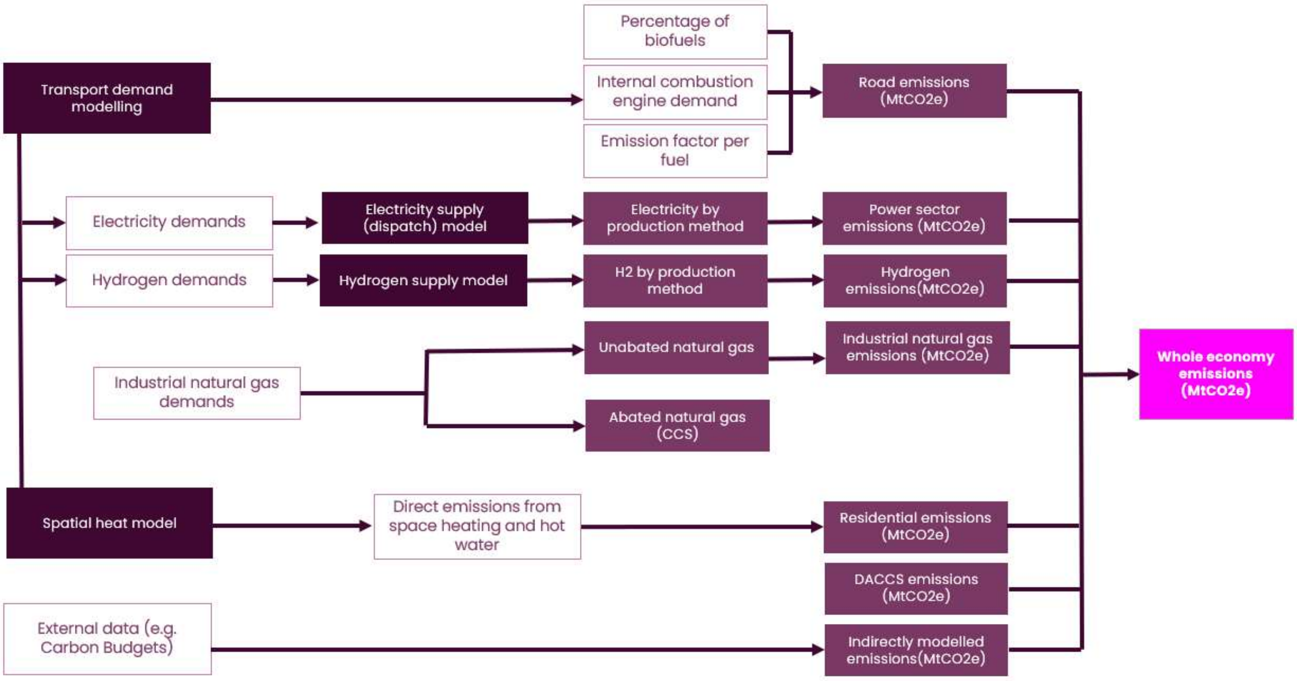

Figure 5: Emissions modelling process

3.4 Economic modelling

Our modelling utilises cost elements and techno-economic information to create the demand and supply solutions. Some of the areas where this is included in the modelling are detailed below.

Road Transport

- Implements a "Bass diffusion" model for the rollout of new technologies and incorporates a total cost of ownership basis for numbers of new vehicles within the modelling.

Spatial Heat Model

- Incorporates a total cost of ownership approach to heating technology uptake for each building archetype within a climate zone (this consists of capital costs for the product, fuel costs to run and any incentives or grants available).
- Functionality to include the costs for hydrogen and district heating network build are included within this - the costs of energy efficiency measures and any thermal storage are included within the total cost of ownership.
- Has functionality to reflect 'willingness to pay' of different consumers which affects uptake based on payback period
- Operation profiles for each technology within the model are influenced by costs (for example, when a time-of-use tariff price profile is implemented, heat

pump demand is shifted away from peak times through thermal storage or hybrid fuel switching to avoid peak prices) - this affects the flexibility within different pathways.

Industrial and Commercial Demand

- Initial stages use an economic model to represent the relationships between energy use, the wider economy (measured by gross value-added) and energy prices across the modelled sub-sectors
- Later stages incorporate the cost of changing to alternative technologies and payback periods for these where commercial and industrial sectors are moving to low carbon alternatives.

Supply Modelling

- New build of electricity generation, hydrogen production and storage assets post-2031 are optimised within the Plexos model to deliver the lowest overall cost solution given the expected demand and any constraints placed on that solution
- Running of electricity generation and hydrogen production, along with utilisation of storage assets, is optimised to meet a given demand in each hour of the year at the lowest overall cost within the bounds of any other constraints placed on that solution.

In each case, the input assumptions on which these models run can vary between pathways and certain functionality may or may not be used in the results.

Building on the economic modelling carried out for our Clean Power 2030 advice, we aim to bring in additional economic analysis and commentary on our pathways through 2025. Further details on scope will be communicated to stakeholders prior to publication.

3.5 Key considerations

How we consider network constraints

Pre-2031, our generation build is based upon the Transmission Entry Capacity and Embedded Capacity Registers. After this point, the impact of electricity transmission network constraints helps inform a suitable regional distribution and mixture of technologies in our CEM. Our model assumes the network capacities as detailed by the second Transitional Centralised Network Plan (tCNSP2) out to 2044. Including these constraints means the model favours colocation of increased generation capacity with large electricity demand, such as electrolysers, to reduce the peak flows of electricity between regions within Great Britain. We do not model constraints in our electricity dispatch model for FES as this is covered in the CSNP process.

We do not model electricity distribution network or gas network constraints in FES. These are considered in downstream network planning processes. We will continue to review our coverage of constraints as strategic network planning develops.

Market indicators, supply chain considerations and finance

While market indicators, supply chain considerations and financeability are not directly modelled in FES, we integrate insights from other NESO modelling efforts and actively incorporate stakeholder feedback. For FES 2025 we will take additional insight from the work carried out in the development of our *Clean Power 2030* advice for the electricity supply sector.

Market indicators, supply chain and finance are key topics on which we seek to engage on with stakeholders. This approach ensures an understanding of external factors influencing the energy landscape, allowing us to develop robust and informed pathways.

Ensuring unbiased analysis

To ensure our analysis is unbiased and robust, our work is based on stakeholder engagement, testing of inputs and outputs, review of other industry pathways and analysis and continuous learning. Engaging a diverse range of stakeholders is crucial for incorporating varied perspectives and challenge potential biases. We test our analytical inputs, assumptions, and results through challenge and reviews and stress testing prior to publication.

Learning from other organisations, such as the CCC, helps us adopt best practices and refine our methodologies.

Additionally, we will maintain transparency by documenting and publishing our assumptions, methodologies, and any changes made based on stakeholder feedback. We will continue to publish our data workbook alongside the FES publication.

3.6 Stakeholder feedback on our modelling

We asked stakeholders for views on the need and value in modelling beyond the 2050 horizon.

A number of stakeholders agreed that modelling beyond 2050 could help accommodate needs for renewable, low carbon and flexible assets taking place in the next 25 years and operating beyond this point. Doing so would also, they felt, enable consideration of ongoing network planning and contingency needs.

Some also noted that any long-term pathways should meet all legally binding targets and support the corresponding accelerated network investments, including those beyond the 2050 timeframe. This may enable visibility of when pathways meet the 2050 target (if not reached by this stage).

When discussing the merits, some discussed how rolling modelling horizons would consider ongoing policy and behavioural changes, and whole lifecycle considerations accordingly; they noted, too, that FES needs to align with other network planning processes (e.g. 25-year rolling horizons which go beyond 2050). Another benefit noted was regarding assets built to last more than 25 years. Technological readiness was also discussed, with some explaining how modelling beyond 2050 could account for all technologies with low technology readiness levels but with the potential to become technologically viable.

Those with concerns cited challenging modelling accuracy, advising that probabilistic ways to cover the uncertainty would be needed. They also queried whether a plan beyond 2050 would rely on negative emissions beyond that point.

NESO's response

In line with our current licence conditions, including C15.3(c) and C10.3(c) of the ESO and GSP licence respectively, FES 2025 will project out to 2050. The criteria for extending our modelling beyond 2050 are:

- Requirements for longer term projections from downstream planning processes
- Setting of emissions and key energy system targets beyond 2050

Should the need arise to develop our pathways to a moving window as set out in the guidance document (for example, 25 years) we would develop our methodology for determining supply and demand projections through engagement with stakeholders.

4 Uncertainty, stress testing, and high impact low probability events

There is significant uncertainty in quantifying the demand and supply in a future energy system out to 2050. In addition to the areas where uncertainty is already captured in the range we present across our pathways and counterfactual, as demonstrated by our framework in Section 2.3, we address this in a number of ways.

4.1 Uncertainty

Uncertainty is addressed by taking in-depth analysis from analysts alongside stakeholder feedback to develop pathways that represent potential future scenarios. Uncertainty distributions are applied to the first five years of our forecast of demand, derived from historical performance, sensitivity to input parameters and expert validation.

The peak demand Monte Carlo statistical analysis investigates the uncertainty surrounding the assumptions made in FES. By randomising these uncertainties, thousands of different permutations of demand are generated, all of which align with the original pathway. When aggregated, these reveal the potential range of total peak demand in the short term. The value of this analysis lies in providing a quantified risk to the security of supply when producing the Electricity Capacity Report (ECR).

For future FES iterations, we are developing our models to consider additional uncertainty in our appliances and industry and commercial sector analysis.

4.2 Stress testing

We include some stress testing in the development of our pathways. A key example of this is in our supply side modelling.

Weather not only determines the level of demand but also the amount of weather-dependent generation on the network. It is important to quantify the impact of weather on the generation output to ensure that it is adequate for our system needs. In our modelling, we need a forecast of how the weather-dependent components of generation and demand will change in each hour across Great Britain. To do this, we assume that:

- Weather-dependent renewable generation (onshore and offshore wind, solar and tidal) follows a regional profile given by the weather patterns recorded from January to December 2013

- Electricity and gas demand follows a regional temperature profile given by the weather patterns from the same year
- This single weather pattern repeats each modelled year from 2023 until 2050 for all pathways and the Counterfactual.

The use of a single representative weather year is common in power system modelling, and we have used this alongside other security of supply metrics, such as Loss Of Load Expectation (LOLE) and capacity margins as a surrogate for sampling a wider range of conditions. We use the year 2013 because it represents a typical British weather year, characterised by low temperatures and high winds in winter and a mild summer.

We have added a reserve margin to CEM which ensures the firm capacity of all generation plants meets peak demand, plus 4% - this means we can ensure our generation capacity mix is applicable for multiple (and even more extreme) weather years.

The FES pathways are then stress tested against a range of difficult conditions in downstream processes. This includes testing a large range of weather years, simulating dunkelflaute events and simulating high demand conditions and limiting imports from neighbouring markets as well as other tests of resilience. For more information on this, please visit pages 5 and 34 of our Assumptions document.

4.3 High impact low probability events

NESO will consider high impact low probability events (HILPs) through a number of processes. We are in the process of identifying a wide range of potential HILP events as part of NESO's wider work spanning all our responsibilities. As part of FES, we will seek to test our pathways against those which could result in significant deviation from the pathways presented. Our intention is to consider forward-looking stress testing, exploring credible risks, opportunities and deviations from the pathways.

Defining HILPs

To define a HILP event, we consider three key questions:

What is an event?

A notable occurrence in a particular place during a particular time, with a distinct start and finish, which often indicates a discernible shift or movement in the trajectory of the future.

Based on the Organisation for Economic Co-operation and Development (OECD) *Framework on Anticipating and Managing Emerging Critical Risk*, NESO considers both precedented and unprecedented events. Precedented events will have precedent and/or a deep knowledge base. Unprecedented events have evolved due to new or unfamiliar conditions or changes in the threat or vulnerability or exposure environment. These events lack precedent, and data may be insufficient to attribute probability to emerging critical risks based on past frequency.

What is high impact?

In this work, high impact will be defined as having immediate effects and significant impacts relevant to the whole energy system.

HILP events have a wide range of often systemic impacts and quantitative impact scoring is not suitable. We will assess the impact of HILP events against dimensions of impact upon sustainability, energy security, affordability, consumer behaviour, and whole system impacts to essential services, economic damage, and human welfare.2 Impact within these dimensions will be considered based on the scope, scale, and duration of the impacts the reasonable worst-case scenario could foreseeably cause.

The impact of a HILP event will also take into consideration its influence upon the occurrence of other HILP events, applying the approach to viewing the interconnectedness of risks which was used in the *Global Risks Report 2025*.

What is low probability?

For this work, we define low probability to describe events that arise randomly and unexpectedly and cannot easily be anticipated. Qualitative methods are the primary approach used to assess probability in this work, recognising both that unprecedented HILPs lack the historic data necessary for quantitative assessment and the fact that the systemic nature of such events make it difficult to generate reliable quantitative estimates.

Qualitative assessment of probability will use subject matter expertise and scenario analysis to give a view of the probability of a reasonable worse-case scenario occurring before 2035. Where quantitative assessments are made available, we will consider events with less than 5% chance of the reasonable worse-case scenario occurring to be potential HILPs and which will require further qualitative analysis. This aligns with thresholds defined by the UK National Risk Register and PHIA Probabilistic

[2] This aligns closely with the impact assessments undertaken in the UK National Risk Register 2025, expanded to include consideration of elements of the Energy Trilemma.

Yardstick[3], where events of under 5% probability of occurring are considered to have a 'remote chance' of occurring.

A phased approach to identifying and exploring potential HILPs

Our methodology uses a phased three-part approach, with each part seeking to expand further on the nuances behind HILPs and their relationship with the energy transition.

What HILP events will we will include for FES?

Over the coming weeks we will review the potential HILPs identified and define those to be used in testing of our FES 2025 pathways.

To give an indication of some of the types of HILP events being reviewed as part of wider activities at this time, examples of case studies which are currently informing analysis of precedented HILP events in this work include:

- Occurrences of severe space weather (for example, those events experienced in 1859 and 1956)
- Extreme meteorological events (for example, 2007 floods, 2013/14 winter storms, St Jude Storm 2013)
- Socio-political events (for example the 1972 miners' strike and 2000 fuel protests).

[3] Developed by the Professional Head of Intelligence Assessment (PHIA) in the UK Government, the Probability Yardstick is designed to standardise the definition of event probability in intelligence assessments. See also: National Risk Register - 2025 edition; Intelligence – communicating probability - GOV.UK

How will we consider HILPs alongside our pathways?

The methodology for considering HILP events will differ depending on the type of event identified. Some events may need to be assessed through changes to levers and assumptions in one specific aspect of the modelling (such as emissions modelling), while others will need to be designed as separate sensitivity scenarios.

In our analysis, we will include a qualitative impact assessment to provide an understanding of the potential effects.

4.4 Stakeholder feedback on uncertainty, stress testing and high impact low probability events

We asked stakeholders for their views on including HILP events in our next publications.

Some felt that HILPs would be helpful for benchmarking models, with others citing investment and helping understand the impact of events upon investment decisions.

It was suggested that any case studies should be examples of potential threats to net zero and should not be built into the pathways. Others assumed that HILP events have been considered to some extent in stress testing the viability of pathways. If included in the pathways, it was suggested it should be clearly explained if it has altered the pathway; they felt that firming the HILP event definition, and its position within the decision-making framework, would help strengthen the design of the pathways. Some suggested that the methodology should consider criteria for a HILP and a sufficiently plausible outcome to be reflected in a pathway. It was suggested that HILP events could focus on different timeframes, between which the framework should then clearly distinguish.

We asked stakeholders for their views on areas of focus for these case studies.

There were a number of suggestions from stakeholders. Views included short-term stresses (for example, extended wind lull or extreme temperatures), medium-term shocks (economic, for instance) and longer-term shifts, including to government policy or changes in demand patterns. Cyber attacks were also among events cited.

Dunkelflaute was raised, alongside plausible weather-related stresses / climate change-driven weather events. Some stakeholders also wanted to see the impact of delays in big infrastructure projects as well as the effect on power networks.

Supply chain was a consideration for some, including the impact of geopolitical events.

Exploring annual investment and markets, operation and constraints were other areas of focus alongside cascading outages.

NESO's response

> We are in the process of defining the HILPs that will be included as part of the FES analysis and will communicate further details prior to publication.

5 Data transparency

Our approach to data transparency

We aim to make as much of the data used in FES publicly available as we can. However, this may not always be possible (for example, if input data sets have been procured with restrictions, we have used data not owned by NESO or if data is commercially sensitive). We will apply open data principles and best practice in determining what data can be shared publicly.

FES data sets are published alongside the report via our website in a data workbook. We also provide data tables in machine-readable format via the NESO data portal.

In FES 2024, we also published a Data Dictionary alongside our key assumptions to increase clarity over input data used in our modelling - we will continue to update and expand this.

The data used in production of our modelling is not static and we will continue to triage and provide new data over time alongside each FES publication or update.

Requesting additional information

Where our data has not yet been made available, or where it is not clear what has been used, our FES email enquiry inbox remains open for data queries.

Where requests for additional data are received, these will be fulfilled where reasonable and in line with the principles of open data, subject to open data triage, and in line with other obligations such as Freedom of Information.

Responses to requests for additional data may either trigger an update and re-release of our data workbook and/or data on the NESO data portal or other route to publicly share as appropriate.

6 Governance

Internal governance process

Effective governance is crucial in developing robust analysis and insightful projections for the future of the energy system. It ensures that the methodologies and assumptions used are rigorously reviewed and validated, fostering transparency and accountability. By involving subject matter experts and stakeholders in the review process, governance helps to identify and mitigate potential biases, enhancing the credibility and reliability of the results. This structured approach not only supports the integrity of the analysis but also builds trust among stakeholders, ensuring that the insights generated are well-founded and actionable.

Key elements of the FES governance process include executive and steering committees, internal and external challenge and reviews, data checks and stage gate sign-off and editorial boards.

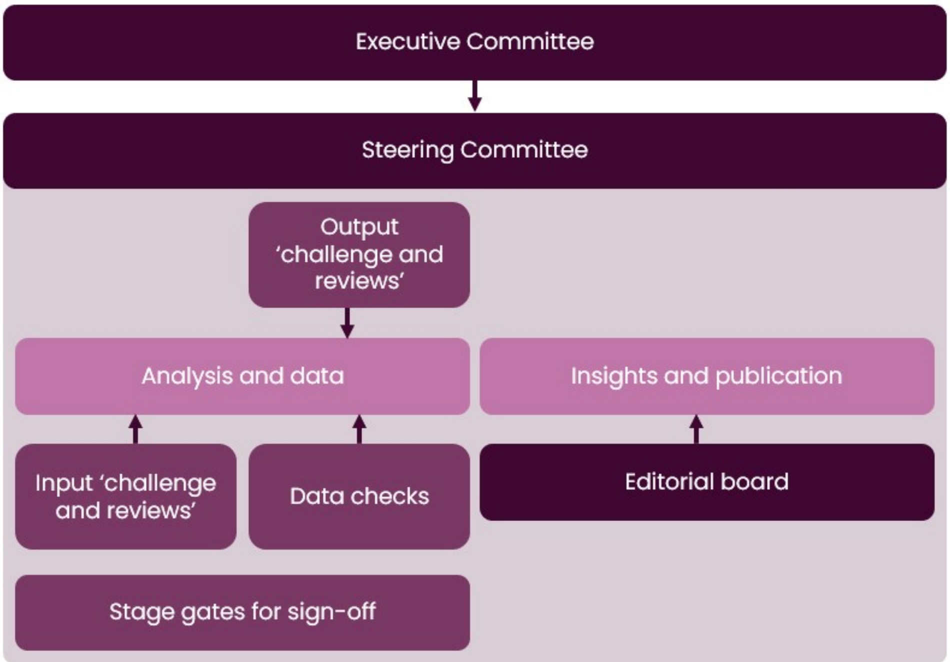

Figure 6: Future Energy Scenarios analysis and publication internal governance process

Governance	Description
Executive Committee	NESO Executive Team Decisions and sign-off of framework, key data and insights and key messages

Governance	Description
Steering Committee	*Senior Leadership across NESO directorates* Steer on emerging data and insights
Challenge and reviews	Internal and external challenge and review of assumptions and levers at input stages and emerging data at output stage
Data checks	Data checks and sign off by area plus "data days" prior to publication to review, check and sign off data as a whole
Stage gates	A series of "gates" at which checks are made on quality and consistency of analysis in order to allow the next stage of the process to be started with senior leadership sign-off
Editorial Board	Representatives from across NESO directorate review the FES publication throughout the drafting process

Inputs, assumptions and decisions

Inputs and assumptions provide the foundational data and context needed to model various scenarios and predict potential outcomes. By incorporating historical data, expert insights and stakeholder feedback, these inputs and assumptions help account for uncertainties and variables that could impact future energy trends. This approach ensures that the forecasts are not only grounded in reality, but also flexible enough to adapt to changing conditions, helping to support informed decision-making and strategic planning. Assumptions are developed through a combination of research and stakeholder engagement and are approved via internal committees (comprised of internal subject matter experts), stakeholder engagement, and/or challenge and review sessions.

Significant inputs, assumptions and decisions may be agreed by an internal FES Steering Committee. Their decision may be required on matters that have a significant impact on strategic energy planning activities downstream of FES.

Assumptions are recorded throughout the FES process and an assumptions document is published alongside the main report.

Models

Our models are under continuous development to ensure they reflect the changing energy landscape and societal changes, or to incorporate new approaches.

Different approaches are taken to enhance our models depending on the scale and significance of the change. Small changes may be implemented by the responsible analyst as part of the process of creating their results (for instance updating field names if these have changed in the inputs or in updating model parameters). Larger changes may involve projects delivered by external parties either through direct contracting or such mechanisms as Innovation funding.

Validation of new and updated models is conducted by comparing previous model outputs, third party results and/or statistical measures of model performance across test datasets or through back-casting. Projects funded through Innovation funding may also have additional measures included in the project criteria that must be demonstrated.

Review and approval on new and updated models is conducted through internal sessions to validate the approaches taken and subsequent results. Where appropriate (and depending on the significance of the change), an external stakeholder review of the approach and output may also be sought through, for example, Network Forums or bilateral meetings to inform internal approval of the models used. Projects funded through Innovation funding are also subject to the governance requirements of the funding route.

We provide an overview of our modelling in our FES: ESO Pathways to Net Zero Modelling Methods 2024 document. This is updated and published alongside each FES publication to reflect changes since the last edition or to enhance clarity.

We are open to feedback and more detailed discussion on how our models work and can be contacted via the FES email address by any party wishing engage in this area.

7 Review and approval of outputs

Once we have provisionally completed our modelling for each sector we hold output challenge and review sessions, where we present our results and rationale for any changes since the previous year. We hold these sessions with an internal audience of experts across NESO, and then with the Network Forum (gas and electricity transmission and distribution networks), Ofgem and DESNZ. We consider any feedback received in the round. We then seek approval for the final dataset using our stage gate process, where process, data quality and consistency are signed off by senior leadership. Following this, the datasets are finalised and handed over to the next team in the process.

Written documents, recommendations and infographics are subject to several rounds of drafting and reviews during development, and approval prior to publication.

8 List of abbreviations

Acronym	Definition
10YF	Ten-Year Forecast
5YF	Five-Year Forecast
CCC	Climate Change Committee
CEM	Capacity Expansion Model
CSNP	Centralised Strategic Network Plan
DESNZ	Department for Energy Security and Net Zero
DG	Distributed Generation
FES	Future Energy Scenarios
GSP	Grid Supply Point
HILP	High Impact Low Probability events
NDCs	Nationally Determined Contributions
NESO	National Energy System Operator
REMA	Review of Electricity Market Arrangements
RESP	Regional Energy Strategic Plan
SEP	Strategic Energy Planning
SoS	Security of Supply
SSEP	Strategic Spatial Energy Plan