Future Energy Scenarios: Pathway Assumptions 2024

ESO

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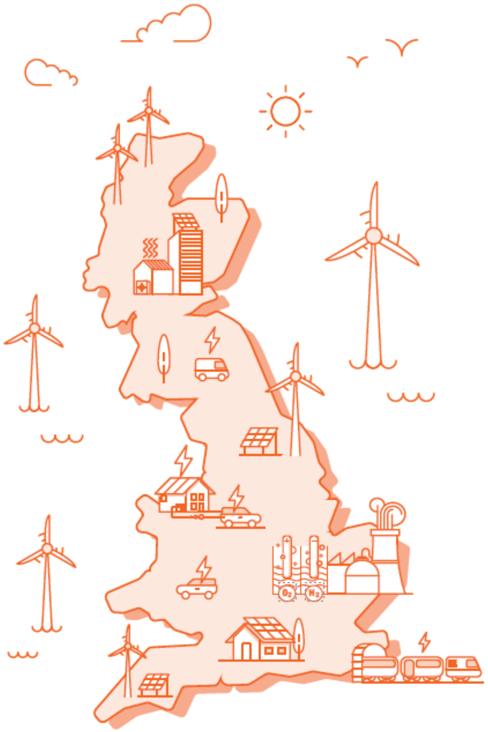

Introduction

Assumptions and assurance are the foundations on which our pathway modelling is built. The energy system is highly complex, with a growing number of interdependent factors. Our assumptions help to define our modelling parameters and highlight areas of uncertainty.

Different inputs and assumptions lead to different outcomes and, by varying assumptions across the pathways, we can explore a range of futures.

This document provides a summary of the key assumptions that can make the biggest difference to our modelling outputs or beliefs on supply, demand and emissions pathways out to 2050.

Further information can be found in our supporting assumptions workbook and our "Future Energy Scenarios: Modelling Methods 2024" and "Future Energy Scenarios: Changes from FES 2023 to FES 2024" documents.

Please refer to the glossary at the back of this document for acronym definitions.

Common assumptions

This chapter covers assumptions that are common across the pathways and the Counterfactual in Future Energy Scenarios: ESO Pathways to Net Zero 2024.

Security of supply

Why is it a key assumption?

Security of supply standards determine whether demand is met in a pathway under stress conditions. Meeting security of supply in all pathways determines the level of generation capacity needed to fulfill hourly as well as peak demand each year.

This is also the starting point in assessing the future network requirements in studies that make use of our analysis for this purpose.

Meeting security of supply is essential to ensure that Great Britain has a resilient network.

How does it affect the modelling outcome?

The security of supply standard used determines the capacity margin that is required in each year of our analysis. This margin is set so that it exceeds, but remains within a tolerance above, the three hours LOLE metric. This ensures that capacity is sufficient to meet demand under stress conditions.

Note that further work on security of supply is carried in our downstream network planning processes.

What is assumed?

We assumed that sufficient generation, storage and interconnection will be built to ensure the security of supply standard of three hours of loss of load expectation (LOLE) per year is met. This assumption applies to all pathways and the Counterfactual. We test this by:

- Measuring against ACS winter peak demand
- Applying derated generation capacities (provided by the National Grid ESO Electricity Market Reform Analysis team)
- Catering for largest infeed loss.

Why have we made this assumption?

Although there is significant uncertainty over future supply in the pathways, modelling to a strict security of supply standard ensures that the generation capacities set out in the pathways and the Counterfactual are sufficient.

Three hours LOLE per year is a Government set standard. More information about this standard can be found here.

Ambient temperature

Why is it a key assumption?

Changes to ambient temperatures and weather patterns due to climate change will have an impact on demand in multiple sectors and on weather-dependent generation.

What is assumed?

Ambient temperature is fixed over the pathway time horizon. There is no temperature increase due to climate change modelled from today's temperatures.

How does it affect the modelling outcome?

An increase in ambient temperature will reduce heating demand and increase cooling demand, whilst also influencing annual demand patterns for both buildings and electric vehicles (EVs). Changes in weather conditions could also affect weather-dependent generation. Changes in weather patterns may alter the ratio of average cold spell (ACS) demand to annual demand, the efficiency of thermal plant etc.

Why have we made this assumption?

There is significant uncertainty over future ambient temperatures and weather patterns across the year. A range of global temperature increases does not currently map to any specific pathway to net zero narrative. This is an area of our modelling that we would like to explore in further detail, particularly the impact of climate change on heat demand.

Population and housing

Why is it a key assumption?

The population and number of homes in Great Britain have a significant impact on energy demand. The projected profile of population and housing stock growth is an important consideration, as are the values assumed for the current state.

What is assumed?

- A fixed profile for the population of Great Britain is applied across all pathways, reaching approximately 69 million by 2050
- A fixed build profile of Great Britain's housing stock is applied across all pathways, reaching approximately 33 million by 2050.

These forecasts and current statistics are taken from housing and population growth projections by Oxford Economics.

How does it affect the modelling outcome?

The higher the housing stock, the higher the energy demand for heating, appliances and lighting. It would also change the average demand and efficiency, as new housing stock is assumed to be more efficient. A larger population would also lead to more vehicles on the road and a higher demand from the transport sector.

Why have we made this assumption?

There is no reason to vary the population and housing numbers across the pathways and doing so would make comparison between the pathways very difficult. We have sourced these values from a reputable third party as we do not model this ourselves.

Emissions

Non-FES sector emissions

Why is it a key assumption?

Making non-FES sector emissions consistent across the pathways means the decisions needed in the sectors we model directly are clearer.

What is assumed?

In our pathways, we have assumed that sector emissions which are not modelled in FES are aligned with the Climate Change Committee's (CCC) Sixth Carbon Budget Balanced Pathway. This means that emissions from these sectors will follow the assumptions and outcomes outlined in the CCC's reporting. The sectors we don't model directly are aviation, agriculture, shipping, land use, land-use change and forestry (LULUCF), waste, F-gases, bioenergy carbon capture and storage (BECCS) for biofuels and fuel supply.

From this assumption we have specific residual emissions for different sectors that we assume cannot be removed and must be offset with negative emissions from the energy sector.

How does it affect the modelling outcome?

Aligning emissions from non-FES sectors with the CCC's Balanced Pathway allows for the calculation of whole system emissions. By 2050, most of the residual emissions come from non-FES sectors. Knowing this helps determine the need for negative emissions in meeting net zero.

Why have we made this assumption?

These are not sectors that the ESO has expertise in modelling (agriculture, for example). By aligning with the CCC's Balanced Pathway and incorporating minor updates to it to reflect progress and revisions since the Sixth Carbon Budget was published, we ensure that our pathways adhere to the same standards for decarbonisation in non-FES sectors as used in the carbon budgets. This provides a consistent base for modelling across FES.

Direct air carbon capture and storage

Why is it a key assumption?

By integrating direct air carbon capture and storage (DACCS) across all pathways, we can evaluate how net zero can be achieved through different types of negative emissions technologies at various levels. In FES 2023, DACCS was only included in one scenario. DACCS and bioenergy carbon capture and storage (BECCS) can provide permanent, metered geological storage and net removal of CO_2 from the atmosphere. Without DACCS, increased BECCS would be required.

Increased BECCS may stress supplies of sustainable biomass resources and increase biomass import dependency. Nature-based carbon removals are assumed from the non-FES sectors such as land use, land-use change and forestry.

What is assumed?

It is assumed that DACCS is included in all net zero pathways in FES 2024. The scale of DACCs varies across the pathways, relative to each pathway narrative. We have assumed between 5–15 $MtCO_2$ of DACCS capacity is available in 2050, with deployment beginning in 2040.

Recent studies for the UK Government have estimated possible 2050 DACCS deployment ranges of 5–25 $MtCO_2$, dependent on the level of carbon removals needed, with most of this deployment occurring in the 2040s.

Direct air carbon capture and storage (continued)

How does it affect the modelling outcome?

DACCS is used with BECCS for permanent carbon removal. This is required to offset residual emissions left in the economy that cannot be decarbonised by 2050.

The level of DACCS is varied as it has a high energy demand. BECCS produces energy vectors alongside carbon removal, however it is limited by available sustainable biomass supply and, by extension, land use. This modelling approach illustrates the trade-offs between DACCS and BECCS across the pathways to achieve net zero and provides insights into how these technologies can complement each other to decarbonise the energy system.

Why have we made this assumption?

There is increased confidence in the feasibility of DACCS deployment, due to UK Government support through the Greenhouse Gas Removal Innovation Competition, as well as the development of large-scale projects in the USA. This is indicating that DACCS is becoming a more viable and scalable solution for carbon removal.

Our assumptions for DACCS deployment scales are on the low-to-medium end of recent UK assessments and timescales for deployment are also well within those of recent UK assessments.

Bioenergy carbon capture and storage

Why is it a key assumption?

BECCS is a source of permanent net carbon removal from the atmosphere. We will require negative emissions technologies to offset the remaining emissions in the economy in 2050 and reach net zero. BECCS and DACCS are the only engineered removal technologies we model. We are aware of others, but they are at a lower technological readiness level (TRL) and have additional uncertainty.

How does it affect the modelling outcome?

By updating BECCS deployment rates, we ensure that our pathways are capable of offsetting increased emissions and meet the Sixth Carbon Budget. Updating BECCS deployment rates impacts modelling outcomes by providing an updated view of the role BECCS can play in achieving net zero emissions. It allows for the assessment of how these updated rates affect overall emissions reductions and how it can compensate for slower emission reductions in other sectors, compared to the FES 2023 scenarios.

What is assumed?

BECCS deployment begins in 2030, in line with the availability of CO_2 transportation and storage capacity through the UK Government carbon capture, usage and storage (CCUS) cluster programme. The overall availability of biomass feedstock acts as an upper constraint on the amount of BECCS that can be deployed. Feedstock availability is taken from the CCC's Sixth Carbon Budget. Deployment rates of BECCS technologies (power BECCS and hydrogen BECCS) have been updated. BECCS for biofuels, such as sustainable aviation fuels (SAF), is a 'non-FES sector' and assumed from the CCC's Sixth Carbon Budget.

Why have we made this assumption?

The updated deployment rates are based on stakeholder engagement, announced power BECCS plans in the UK, likely timing of power BECCS business models and CO_2 storage pipelines, as well as historical rates of biomass power construction or conversion in the UK. Hydrogen BECCS deployment is slower and smaller-scale, reflecting the lower confidence in this technology and that it is the subject to the UK Government funded Hydrogen BECCS innovation programme. By incorporating these changes, we ensure that our pathways meet the Sixth Carbon Budget and net zero.

Energy demand

Hydrogen availability for heating

Why is it a key assumption?

The uptake of hydrogen for heat has a significant effect on the level of overall hydrogen demand. The availability of hydrogen for heating is uncertain prior to a policy decision and is dependent upon support for hydrogen production and distribution, cost and the success of trial projects.

What is assumed?

The Counterfactual and our Electric Engagement pathway have no hydrogen for heating. Holistic Transition assumes that hydrogen for heating develops close to hydrogen production locations associated with industrial clusters from 2030.

Hydrogen Evolution assumes high levels of policy support for hydrogen, starting in 2030 around industrial clusters and growing to a national hydrogen transportation network by 2050.

How does it affect the modelling outcome?

The assumptions made about the uptake of hydrogen for heat have a significant impact on overall hydrogen demand across the pathways. A pathway with wider access to hydrogen networks will see higher overall levels of demand. With slower development of hydrogen networks, other technologies need to be installed to meet emissions targets.

Why have we made this assumption?

No decision has yet been taken regarding the use of hydrogen for residential heating, meaning it is appropriate to continue to explore a range across the pathways.

Changes to network build out are in line with stakeholder feedback on regional development of networks.

Fossil fuel boiler phase-out date

Why is it a key assumption?

The assumptions made here affect whether fossil fuel boilers remain a choice for consumers as new heating solutions within our modelling.

What is assumed?

All our pathways include a phase-out of the sale of fossil fuel boilers until 2035. Boilers (gas and oil) are prevented from being adopted from 2035 onwards. Since boilers in the model have a lifetime of 15 years, this means there are no fossil fuel boilers left on the system in 2050.

The Counterfactual does not meet net zero and assumes that no phase-out of fossil fuel boilers is implemented.

How does it affect the modelling outcome?

These assumptions affect the number of fossil fuel boilers on the system in 2050 and, therefore, the energy demand and emissions from these boilers.

Why have we made this assumption?

A full phase-out on the sale of new fossil fuel boilers matches the original UK Government policy in this area, but exceeds a revision made in 2023, reducing this to an 80% phase-out of sales. We assumed a full phase-out to ensure that the modelled outcome has completely removed fossil fuel boilers from the system by 2050. Boilers could be installed after the 2035 date and still be off the system by 2050, but this would require replacing these before the end of their lifetime, which our modelling does not currently facilitate.

Industrial fuel switching

Why is it a key assumption?

Current levels of fossil fuel use in the industrial sector are significant and fuel switching needs to take place at a fast pace to meet the Sixth Carbon Budget through any combination of electrification or hydrogen. The assumptions drive a range of fuel use across the pathways.

How does it affect the modelling outcome?

The choice of industrial fuel switching alters hydrogen demand by 62 TWh and electricity demand by 46 TWh when comparing Hydrogen Evolution and Electric Engagement in 2050.

What is assumed?

Each pathway is matched in its fuel switching to where it sits on the FES 2024 framework. Electric Engagement and the Counterfactual assume a slow and minimal level of fuel switching to hydrogen. Electric Engagement assumes high levels of electrification. Hydrogen Evolution assumes only a small amount of fuel switching is to electricity and that decarbonisation is predominantly from hydrogen use. Holistic Transition is positioned between the other two pathways, assuming moderate additional electrification but reasonable growth in hydrogen in industry.

Why have we made this assumption?

The pathways cover a range of fuel switching use in industry to reflect uncertainty in access and levels of use of hydrogen in industry. This is to reflect that industrial fuel switching is a priority use of hydrogen and that some industrial processes may be challenging to decarbonise without the use of hydrogen, whilst others may have alternative options.

Data centre growth

Why is it a key assumption?

Data centres have become a source of significant demand in our modelling, taking account of the rapid growth of this sector. They make up a large percentage of commercial sector energy demand and their potential growth can drive a substantial range in outcomes across the pathways.

How does it affect the modelling outcome?

This has changed substantially from our FES 2023 approach, with greater emphasis and analysis around post-2035 growth in the data centre market. The more operational data centres and the greater the workload placed upon them via changes in their customer base, the greater this impact will be. The wide range of potential future data centres results in the high ranges of 27 to 62 TWh in final energy demand from data centres.

What is assumed?

The number of data centres and their associated demand connecting to the distribution and transmission networks. This is initially based on the registers of planning and grid connection applications for all available new data centres. We include a range on the number of future projects and the speed of completion. Higher data centre demand is mapped to the pathways with higher use of consumer engagement with smart technologies, with Holistic Transition the highest and the Counterfactual the lowest.

Why have we made this assumption?

The assumptions made are based on stakeholder feedback from the industry and an in-depth review of the connection and planning registers for new data centres in Great Britain. We included a wider range of pathway outputs based on the inherent uncertainty regarding future growth of this sector and the possibility that such growth may not take place as rapidly or to the scale expected due to potential issues over planning, grid connection and external competition with facilities outside the UK.

Efficiency of lighting and appliances

Why is it a key assumption?

Residential electrical appliance efficiency is a key driver for the range of outcomes of residential appliance demand across the pathways.

The assumption on the rate at which bulbs transition to light-emitting diodes (LEDs) is the key driver of the rate of demand reductions in this sector in the short term.

What is assumed?

Residential appliance demand out to 2030 is based on energy consumption in the UK (ECUK) demand per appliance.

We use the lower confidence bound forecast value and upper confidence bound from an exponential smoothing model across the pathways, in line with consumer engagement. Post-2030, we slow the annual demand per appliance year-on-year rate of change by a factor in line with the level of consumer engagement in the relevant pathway, with 0.75 for Holistic Transition and 0.5 in Electric Engagement and Hydrogen Evolution (1 = no slowing).

We follow the Department for Energy Security and Net Zero (DESNZ) projections for bulb installations, which is that 92% of bulbs will be LEDs in 2030.

Efficiency of lighting and appliances (continued)

How does it affect the modelling outcome?

These appliance and lighting efficiency assumptions are responsible for a 15–19 TWh reduction in annual demand across the pathways by 2030. This equates to a 24% reduction in appliance demand in Holistic Transition. The rate at which the bulbs transition to LEDs is a key driver of this.

These assumptions are responsible for an annual demand difference of ~6 TWh between the pathways in 2040.

Why have we made this assumption?

Current EU efficiency directives and UK policies drive efficiency improvements. The UK Government is consulting on achieving 140lm/W weighted average sales of bulbs by 2027 (the best bulbs today are 200lm/W) and has set new energy performance labelling. The pathways have various levels of consumer engagement in energy efficiency and, as such, we assume consumers place varying levels of importance on this in their purchasing decisions.

Air conditioning growth

Why is it a key assumption?

Residential air conditioning units represent a potential new growth of electricity demand in the pathways. The number of units installed and their demand could be significant. Great Britain's housing stock does not typically have air conditioning installed. It is, however, commonplace in countries with a warmer climate and in commercial British buildings to maintain thermal comfort in the warmer months. As global warming leads to average temperatures and the probability of periods of extreme heat increasing, this could drive uptake in Great Britain. However, this is highly uncertain.

What is assumed?

We have assumed a range across the pathways. There is no growth in the level of residential air conditioning units installed in Holistic Transition. In Hydrogen Evolution and Electric Engagement there is growth, which leads to 10 million properties with air conditioning units in 2050. Each pathway assumes the same annual demand per unit, based on an average of 191 running hours and an average unit rating of 2.7kW.

How does it affect the modelling outcome?

It drives an increase in annual demand of 5 TWh for Hydrogen Evolution and Electric Engagement, with 10 million units installed by 2050.

Why have we made this assumption?

The "Cooling in the UK" report suggests that, in a 1.5°C global warming scenario, there may not be any growth of air conditioning units for much of Great Britain. Studies also show a large potential to adopt passive cooling measures and changes in building design to increase comfort. Holistic Transition assumes that society adopts these measures and does not see an uptake in air conditioning. In pathways with lower consumer engagement, we assume a growth in air conditioning. The uptake level benchmarks against the DESNZ MacKay Carbon Calculator ambition Level 2 lever assumption.

Demand side response capacity

Why is it a key assumption?

There is uncertainty, even in the short term, on the sustainable levels of provision of demand side response (DSR) and how rapidly consumers can engage with the various incentive mechanisms. Engagement levels rely on many consumer factors including awareness, willingness, availability and adoption of smart technologies. These factors have been highlighted by the reduction in provision from industrial customers after the removal of the triad payment mechanism, which was a big driver of response over peak.

How does it affect the modelling outcome?

This is a large driver of the volume of flexibility at peak times, which has up to 13 GW impact on the levels of peak demand and the requirements for flexibility. Lower levels of flexibility from DSR will require greater flexibility to be sourced from other more conventional providers, such as batteries or natural gas.

What is assumed?

The amount of demand that residential, industrial and commercial sectors are capable of flexing varies across the pathways in line with consumer engagement levels. These are up to 20% of the entirety of the peak demand and 30% of residential demand in Holistic Transition. The ranges are influenced by feasibility and market rules, including consumer participation in responding either to supplier time of use tariffs (ToUTs) market signals or to external commands from aggregators or system operators. Some consumer flexibility aspects, such as EV and domestic batteries, are captured in separate models.

Why have we made this assumption?

These assumptions were led in part by extensive stakeholder engagement, including aggregators and industrial parties taking part in DSR. We also used evidence from current DSR markets, such as the capacity market (CM) and the ESO ancillary service products like short-term operating reserve (STOR) and demand flexibility service (DFS) to research the sources and behaviour of existing providers. These assumptions capture the uncertainty around this by providing a wide range of potential outcomes across pathways.

Growth in zero emissions vehicles

Why is it a key assumption?

Decarbonisation of the transport sector is one of the immediate primary opportunities for decarbonisation and the electrification of fossil fuels. This in turn reduces emissions as the energy sector decarbonises. It is key in our modelling for emissions and electricity annual and peak demands. The speed of adoption of electric and hydrogen vehicles is directly linked to the growth of demand from each of these fuels in the road transport modelling. HGVs are responsible for a high amount of transport demand due to their heavier weight and high mileage.

How does it affect the modelling outcome?

All pathways now have the same electricity demand from cars out to 2040. Overall, transport adds 101–127 TWh of electricity demand by 2050. The hydrogen HGV demand range in 2050 is between 1 TWh and 40 TWh.

What is assumed?

All pathways follow the zero emission vehicle (ZEV) mandate for the percentage of battery electric vehicle sales in the car and van sectors. The following assumptions are common across all pathways: the overall size of the market follows The Society of Motor Manufacturers & Traders (SMMT) central forecast; no hydrogen is used in cars or vans and common annual mileage is assumed across pathways. Hydrogen is solely used in HGVs above 26 tonnes in Hydrogen Evolution and at a low level in HGVs under 26 tonnes. Other pathways use a lower level of hydrogen in HGVs.

Why have we made this assumption?

The ZEV mandate sets a clear strategic route to decarbonisation. All pathways decarbonise at the same speed. Hydrogen is not used in the cars or vans modelling due to a decreasing number of hydrogen car sales and stakeholder feedback that they didn't believe there would be any use of hydrogen in light vehicles at scale. Hydrogen use in HGVs still presents some uncertainty. Development of electric HGVs is growing, but hydrogen offers a solution for the vehicles to cover longer distance with quicker refill times. There is uncertainty around growth in refilling stations meeting unknown levels of demand. The uncertainty is reflected in the range of the use of hydrogen across the pathways.

Smart charging and vehicle-to-grid

Why is it a key assumption?

Smart charging engagement levels reduce the peak demand from the transport sector.

Vehicle-to-grid (V2G) can offer a significant proportion of the flexibility across the energy system, providing similar system flexibility benefits to electrolysers in Holistic Transition.

What is assumed?

For smaller vehicles, we assume smart charging and V2G only occur at residential chargers. We assume current levels of residential smart charging engagement are 36%.

The pathways then project different levels of consumer engagement, with smart charging depending on the narrative of the pathway. In 2050, engagement levels of smart charging at peak are:

- 83% in Holistic Transition
- 68% in Electric Engagement
- 56% in Hydrogen Evolution
- 45% in the Counterfactual.

We assume HGV depots engage with smart charging. For V2G we assume 72% of cars have access to residential charging. Engagement levels in V2G by 2050 are:

- 45% in Holistic Transition
- 26% in Electric Engagement
- 12% in Hydrogen Evolution.
- 5% in the Counterfactual

We assume 50% of those engaged with V2G are plugged in at peak.

Smart charging and vehicle-to-grid (continued)

How does it affect the modelling outcome?

Smart charging reduces peak demand by up to 16 GW in Holistic Transition in 2050. V2G has a 32 GW capacity at peak in Holistic Transition in 2050. Combined, this lower peak demand provides 48 GW of reduction and decrease the need for firm capacity from other sources, while maintaining security of supply requirements.

Why have we made this assumption?

We have a wide range of smart charging and V2G engagement levels across the pathways to represent the uncertainty in this field. Holistic Transition has the highest engagement levels as this is in line with the pathway narrative. V2G offers a lower cost solution to flexibility than many competing methods and can therefore bring benefits for the energy system and consumers.

Energy supply

Supply technology costs

Why is it a key assumption?

In previous FES cycles, the generation and storage mix was defined using connections registers and stakeholder engagement, adjusted to meet security of supply and scenario narratives. For our FES 2024 pathways, we have implemented a capacity expansion model that requires new assumptions around the cost of future generation and storage technologies from 2030 to 2050.

What is assumed?

We assume that the build costs, operating costs and cost of capital for future generation and storage technologies are aligned with the DESNZ costing data from the Levelised Cost of Electricity project (2023).

We assume that, in combination with the fuel and commodity price assumptions (see slide 29), this provides a valid comparison of the relative costs of energy supply and storage technologies.

How does it affect the modelling outcome?

The transmission electricity capacity expansion model uses these assumptions to determine the lowest cost mixture of transmission connected generation and storage in each of our pathways beyond 2030, subject to build constraints and policy targets.

This capacity is in addition to that assumed on the transmission and distribution networks from the expected pipeline of projects (see slide 31).

Why have we made this assumption?

This assumption has been made to provide a transparent comparison of the potential costs of future supply and storage technologies. For this purpose, we have used DESNZ data as it is publicly available, open to scrutiny and peer reviewed.

Electricity network infrastructure

Why is it a key assumption?

In the new electricity transmission capacity expansion model, we have made assumptions about the amount of electricity that can be transferred between different regions across Great Britain and to neighbouring countries via interconnectors.

What is assumed?

In the electricity capacity expansion model, we have included the expected network constraints, assuming the network build set out in the Holistic Network Design and the Holistic Network Design Follow-up Exercise and the latest published onshore network reinforcement. No further network expansion was included beyond this within the model.

In the dispatch model, we do not include these network constraints.

The capacity of interconnection between Great Britain and Europe is included in both the electricity capacity expansion and dispatch models but varies by pathway in accordance with the pathway narrative. The primary driver of this variance is renewable installed capacity, with Holistic Transition having the highest level of interconnection, followed by Electric Engagement, Hydrogen Evolution and the Counterfactual.

Network outages are not individually modelled either within Great Britain or for the interconnectors. Planned and unplanned network outage rates contribute to the firm capacities included in the Security of Supply standards (see slide 5).

Electricity network infrastructure (continued)

How does it affect the modelling outcome?

The amount of network infrastructure results in regional limits on the generation that is dispatched, which also acts as a soft limit on what new generation can be included within a region.

Why have we made this assumption?

The amount of network infrastructure in the Holistic Network Design and the Holistic Network Design Follow-up Exercise are expected expansions of the existing network with known impacts. Not including additional network expansions beyond these ensures that dispatch of generation reflects known network capacity.

FES forms part of the transmission network design process. As such, when further information comes out of this process, it is fed back into the next FES iteration.

Prices - carbon and natural gas

Why is it a key assumption?

Carbon pricing is a policy instrument that captures the external costs of emissions. A price on carbon can alter actions within a market and enhance the economics of low carbon technologies.

The price of natural gas over time in Great Britain and Europe will have an impact on its usage in the energy sector as well as investment decisions on new fossil fuel generating assets and therefore the rate of decarbonisation.

What is assumed?

We take an average of Aurora and Oxford Economics price forecast for their respective high, base and low cases for carbon and natural gas in both Great Britain and Europe. Different cases are then used across the pathways.

For Holistic Transition, all carbon and gas prices use the high case. For Electric Engagement and Hydrogen Evolution, all carbon prices use the base case and all gas prices the high case. However, the price used for EU gas prices in Hydrogen Evolution is slightly lower than in the other two pathways. For the Counterfactual, all carbon and gas prices use the low case. We assume that the carbon price for Europe and Great Britain converge as the British carbon price support scheme ends in 2030.

Prices - carbon and natural gas (continued)

How does it affect the modelling outcome?

Combined, these two prices drive the balance in build and dispatch of carbon emitting versus low carbon generation forms. They are therefore fundamental to determining the future energy mix both in Great Britain and Europe. The balance of generation types between the two markets will also influence interconnector flows.

The additional pricing offset from British carbon prices support scheme is assumed not to be renewed in our pathways post-2030. This result in the price of carbon in Great Britain broadly aligning to the EU Emissions Trading Scheme.

Why have we made this assumption?

Recent geopolitical events have changed the landscape for gas supply and demand and caused prices to rise. We assume higher prices in our modelling to reflect this.

We explore the impacts of different levels of carbon price by simulating high and low values in Holistic Transition and the Counterfactual respectively.

Project pipeline assessment

Why is it a key assumption?

Our pathways need to reflect the projects that are already part of the electricity capacity registers and have an increased likelihood of delivery. We need to balance these with a high attrition rate and the need to reflect longer-term planning beyond the horizon of these registers. We therefore split our timeline into the pre-2030 period, which is driven by short-term project intelligence and the post-2030 period, where we use economic assessment (see slide 26) supported by a skeleton of minimum projects that have a high likelihood of completion. Our FES pathways are insensitive to the success or not of specific projects and are not intended to reflect judgement beyond the typical attrition rates of projects at certain stages within regions.

How does it affect the modelling outcome?

This sets the level of transmission connected generation and storage present in our pathways up to 2030. Beyond 2030, it sets the sub-set of projects that could be built. For distributed generation, this sets the baseline, but does not limit the future expansion of the different technologies.

What is assumed?

For transmission connected generation, interconnectors and storage we assume the capacity registers represent the projects considered in the pathways pre-2030. If a project is not in a capacity register, then it is not included in this view. Projects that have been successfully awarded support are considered more likely to go ahead. All projects are assessed individually and equally within a region where they are at equivalent stages of development. The closer to delivery, the higher likelihood of inclusion our pathways pre-2030. For distributed generation the baseline is taken from the embedded capacity registers (ECRs). A growth rate is then applied, which allows additional projects to be built.

Why have we made this assumption?

For transmission connected generation with long lead times, it is unlikely that projects not currently in development could be built pre-2030. We think it is important to have a fair and unbiased assessment process for selecting projects for inclusion in the pathways. For distributed generation we limit the ambition in particular regions of some of these small-scale technologies, e.g. rooftop solar, that have short lead times and are sensitive to changing regional policies.

Key project build restrictions

Why is it a key assumption?

These assumptions override the optimisation in our economic model, used to set capacity beyond 2030.

They represent instances where factors not considered by our economic model, such as whole system benefits, regional restriction or policy targets, are included through direct intervention in the modelling outcome.

How does it affect the modelling outcome?

Limiting the model creates an output that is more compatible with the specific nuances and realities of the British energy system. Restricting our economic capacity build model prevents it from building a disproportionate amount of a single technology in a particular region.

The minimum build targets do not restrict the model from building additional capacity if it sees this as being cost optimal.

The nuclear minimum build rates have increased the range of nuclear installed capacity beyond what was seen in FES 2023.

What is assumed?

For several key technologies we set restrictions, which include:

- Nuclear (national minimum build limits and regional restrictions)
- Offshore wind (fixed build to 2034)
- Long-duration energy storage (national minimum build limits)
- Solar (regional maximum annual build limits)
- Hydrogen and CCS gas (infrastructure coupling restrictions which drive the percentage split depending on pathway narrative).

Why have we made this assumption?

We have assumed minimum build targets for nuclear to reflect increased policy targets from the Government. The deployment of offshore wind before 2034 is linked to the expected development of the offshore network. This recognises the significant committed investment in infrastructure. It avoids building offshore wind in locations that are unlikely to have the required onshore connections. We have assumed minimum build targets for long-duration storage to reflect that it is an emerging technology and its potential to provide electricity is independent of weather conditions. Stakeholder engagement, market intelligence and the pathway narratives inform the limits set.

Energy storage

Why is it a key assumption?

Energy storage (excluding hydrogen and Vehicle-to-Grid) is key to enabling system flexibility, balancing the power system and contributing to the development of a low carbon and secure energy system. Considering how to effectively model the impacts various storage technologies can have is therefore crucial to understanding a renewable-led energy system. In the past year there has been a significant increase in the number of battery projects on the capacity registers and in those that have achieved some form of support mechanism. It is important our analysis reflects this.

How does it affect the modelling outcome?

This has led to a much quicker rollout of battery projects than in FES 2023. However, the role of hydrogen storage, as detailed later in the pack and not included here, has led to a reduced build rate for electricity storage in the Hydrogen Evolution pathway. The growth in storage closely follows the rollout of renewables across the pathways.

Vehicle-to-Grid and heat storage are considered in other areas of our assumptions and modelling.

What is assumed?

We have limited our future energy storage technologies to different duration Li-ion batteries, pumped hydro storage, liquid air and compressed air energy storage. We assume that if a project has a capacity market contract, it will be delivered. In Holistic Transition this is assumed to happen in their scheduled year. In other pathways we apply various delays to reflect uncertainty, with the Counterfactual assuming the most delay. We assume growth in storage is tied to growth in renewables.

Why have we made this assumption?

The costings that we have for the included storage technologies are consistent and taken from the DESNZ data set. Including novel storage technologies with limit cost data could risk skewing our results. Historically, projects that have the financial certainty of a capacity market contract are typically delivered. However, delays can frequently occur. This uncertainty is captured within our modelling. Battery storage is often co-located with renewable generation. In addition, greater certainty in delivery of renewable projects creates a greater incentive for battery storage projects to be built.

Weather

Why is it a key assumption?

Weather not only determines the level of demand, for example our heating or air conditioning demand, but also the amount of weather-dependent generation we will see 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.

How does it affect the modelling outcome?

This determines how much generation comes from the installed capacity of renewable sources and the levels of weather-dependent demand in each year of the model run. Any differences between generation and demand need to be made up from other generation or storage sources, curtailment or imports and exports. The hourly generation and demand profiles are needed to correctly quantify the output of renewable generation and the performance of system and demand flexibility during representative periods of system stress.

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.

What is assumed?

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:

- 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 our pathways and the Counterfactual.

Why have we made this assumption?

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 LOLE (see slide 5), 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.

Liquefied natural gas availability

Why is it a key assumption?

Liquefied natural gas (LNG) will play a role in Great Britain's gas supply mix over the outlook period as production from the UKCS and imports from Norway fall. Assuming that LNG imports can run as high as Great Britain's LNG import capacity means that the supply doesn't place any limitation on demand.

How does it affect the modelling outcome?

Due to the high level of LNG availability modelled, LNG can meet total generic imports in any year in any situation, which was not the case in FES 2023. If we were to assume, for example, that LNG imports were in line with our FES 2023 outlook, Great Britain's ability to import LNG would be lower and therefore the 'generic imports' category would also have to be lower, which would force an increase in continental imports.

What is assumed?

We don't expect the availability of LNG supply to place a limit on the amount of LNG that Great Britain can import in any of the pathways or the Counterfactual. When modelling the supply-demand balance outlooks for each of the pathways and the Counterfactual, it is the regasification capacity of Great Britain that sets the ceiling for the maximum level of LNG that the country can import on an annual basis. In FES 2023, it was considered that there was very little surplus LNG that could be directed to Great Britain in the short term. This was because global LNG output capacity only slightly exceeded total contracted volumes. However, this is not taking into account the flexibility of those contracts and the market.

Why have we made this assumption?

There is an increase in certainty around the global LNG market being large and flexible enough to fulfil Great Britain's LNG import requirements in all our pathways. This has come from a better understanding of the nature of LNG contracts and future global LNG production. Great Britain's market buying power being relative to other LNG importers, along with a lack of ability to fuel switch especially in the short term, has led to the assumption that Great Britain will be able to secure sufficient LNG volumes in all pathways.

Barents Sea gas

Why is it a key assumption?

This assumption allows for a significant increase in the volume of gas coming to the British market due to the additional yet-to-find volumes available for export from Norway in the Counterfactual narrative. It is estimated that 65% of Norway's yet-to-find gas is in the Barents Sea. Along with supply from the UKCS, supply from Norway is considered the lowest cost source of natural gas and therefore will be the last source of supply to be 'turned off' once demand reaches a sufficiently low level. The greater volume of gas Great Britain receives from Norway, the less demand there is for imports from LNG or from the continent.

What is assumed?

It is assumed in the Counterfactual narrative that all yet-to-find volumes in Norwegian waters, including the Barents Sea, have the potential to contribute to the flow of gas to the Great Britain. There are currently no pipelines connecting the Barents Sea to the gas pipeline infrastructure further south that would allow for Barents Sea gas to be exported to Great Britain, therefore it is assumed that a pipeline linking up the Barents Sea is built. The opposite is assumed in our pathways.

How does it affect the modelling outcome?

This assumption results in an additional 79 bcm of gas to Great Britain imports from Norway between 2028 and 2050 in the Counterfactual. This limits the level of 'generic imports' in the Counterfactual by displacing some of the generic import volumes with Norwegian imported gas volumes. Generic imports are considered the marginal supply element in the modelling process.

Why have we made this assumption?

This option is under consideration by the Norwegian government. However, such a large investment (an estimated $5 billion pipeline project) would be unlikely in a pathway where Great Britain's gas demand falls rapidly. In the Counterfactual, gas demand is only expected to fall 14% between 2024 and 2050. It is expected that this would provide Norway with a sufficiently large and long-term demand market to justify investing in such a large infrastructure project.

Northwest European regasification capacity

Why is it a key assumption?

Much of Northwest Europe's new regasification capacity is from floating storage and regasification units (FSRUs) which are on 10–20-year charters. These FSRUs could leave Northwest Europe once the charter period ends. This level of regasification capacity in Northwest Europe would allow imports to Great Britain through the interconnectors to run at maximum capacity if required. Interconnector imports will become a very important source of supply flexibility, especially as production from the UKCS and imports from Norway fall. Assuming that continental imports can run as high as Great Britain's interconnector import capacity means that there is no limitation placed on demand by supply levels.

How does it affect the modelling outcome?

This assumption drives the maximum level of potential continental imports in our outlooks. If we were to assume, for example, that Northwest European regasification capacity was in line with our FES 2023 outlook, Great Britain's ability to import gas from the continent would be severely limited and therefore the 'generic imports' category would be lower.

What is assumed?

It is assumed that regasification capacity in Northwest Europe (France, Germany, Belgium and the Netherlands) will remain at close-to-2024 levels of approximately 100 bcma out to 2050.

Why have we made this assumption?

In our previous FES outlook, Northwest European LNG capacity was much lower. However, since the cessation of Russian piped gas imports to Northwest Europe, regasification capacity has increased rapidly. This assumption considers the most likely outcome based on forecasts from third party sources and the expectation that Russian piped gas will not return to Northwest Europe in the future due to current EU policies, such as REPowerEU. Therefore, Northwest Europe will have to maintain a high level of LNG import capacity to ensure security of supply.

Hydrogen production technology costs

Why is it a key assumption?

Cost data is an intrinsic part of the hydrogen capacity expansion module (H-CEM), used to define the build out of hydrogen assets. The cost data directly impacts on which technologies will be selected to be deployed by H-CEM.

How does it affect the modelling outcome?

Previous years' modelling was based on stakeholder engagement and project intelligence, while this year there is more of an emphasis on modelling the economic factors in deploying different supply technologies. The H-CEM model applies an optimiser to solve capacity build at the least cost, subject to other constraints. This requires the assumptions on costs as a key building block.

As costs are the basis of the H-CEM model, their level and evolution over time will have fundamental impacts on the final results. If costs are too high, certain technologies and options may not be taken. Conversely, if set too low, the technology may dominate to an unrealistic extent.

What is assumed?

We have made assumptions on the CAPEX, OPEX and overall delivery and operational costs linked to the production of hydrogen. We have also considered the way costs change over time within the time frame of the pathways. All pathways use the same cost projections. These assumptions are based on the core inputs from DESNZ's cost estimates, published here.

Why have we made this assumption?

This assumption has been made to provide a transparent comparison of the potential costs of future supply and storage technologies. For this purpose, we have used DESNZ data as it is publicly available and peer reviewed.

Hydrogen networks and storage

Why is it a key assumption?

The assumption on how a potential hydrogen transport and storage network grows affects where and when industry, homes and businesses have large-scale access to hydrogen.

How does it affect the modelling outcome?

The assumption leads to a slower network development than that shown in the System Transformation in FES 2023. The existence of a network allows for supply to be located further from sources of demand as well as be shared around more demand centres.

What is assumed?

We have assumed both the initial starting points of a hydrogen network and the potential routes for its development, including the connections to storage assets. We assume the network would grow from industrial clusters.

Our economic model then determines the extent of the hydrogen network needed.

Why have we made this assumption?

These assumptions and parameters have been developed through stakeholder engagement and market intelligence around project pipelines and funding.

We have made this assumption because a network could not be developed without some ‘direction’ or achieved immediately.

Carbon capture and storage-enabled hydrogen growth

Why is it a key assumption?

We model the production of hydrogen to meet demand, which also optimises how hydrogen supply expands geographically. This drives the supply range across all pathways, with the assumption that in the early years a large percentage of the hydrogen supply will come from CCS enabled hydrogen rather than other technologies.

How does it affect the modelling outcome?

We now have greater levels of CCS enabled hydrogen across our net zero pathways than in FES 23 with these projects making up the majority of early low carbon hydrogen production.

What is assumed?

It is assumed that hydrogen demand will grow from industrial clusters and CCS enabled hydrogen production will deliver hydrogen at the pace and scale needed for industry. We assume that assets closest to industrial clusters will be delivered first. We also assume that CCS pipelines will be available for these projects.

Why have we made this assumption?

The initial focus for hydrogen production is expected to be for industrial decarbonisation. Stakeholder engagement and feedback has driven the adoption of this assumption, with further input from the economic modelling for deployment of supply technologies within the economic model beyond 2030.

Glossary

Acronym	Description
ACS	Average Cold Spell
bcm	Billions Cubic Metres
BECCS	Bioenergy Carbon Capture and Storage
CCC	Climate change committee
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Usage and Storage
CM	Capacity Market
CO_2	Carbon Dioxide
DACCS	Direct Air Carbon Capture and Storage
DESNZ	Department of Energy Security and Net Zero
DFS	Demand Flexibility Service
DSR	Demand Side Response
ECUK	Energy Consumption in the United Kingdom
EV	Electric Vehicles
FES	Future Energy Scenarios
FSRU	Floating Storage Regasification Unit
GW	Gigawatt
H-CEM	Hydrogen Capacity Expansion Module

Acronym	Description
HGV	Heavy Goods Vehicle
kW	Kilowatt
LED	Light Emitting Diode
LNG	Liquefied Natural Gas
LOLE	loss of load expectation
LULUCF	Land Use, Land-Use Change and Forestry
PV	Photovoltaic
SAF	Sustainable aviation fuels
SMMT	The Society of Motor Manufacturers and Traders
SMR	Small Modular Reactor
SoS	Security of supply
STOR	Short-Term Operating Reserve
TOUT	Time-of-Use Tariff
TRL	Technological Readiness Level
TWh	Terawatt Hour
UKCS	UK Continental Shelf
V2G	Vehicle-to-Grid
ZEV	Zero Emission Vehicle

Email us your queries and views on Future Energy Scenarios: Pathway Assumptions 2024 or any of our future energy documents at: fes@nationalgrideso.com.

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