Modelling Methods

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Our **Modelling Methods** publication is just one of a suite of documents we produce as part of our Future Energy Scenarios (FES) process. A huge amount of work including modelling, analysis and interpretation goes into the production of the main document. For ease of use we only highlight significant changes to our modelling methods in the main **FES** document. Alongside this publication we have the **Scenario Framework** that details all the assumptions and levers that are used as input into our models. Our **Charts Workbook** contains all the outputs from the numerous models; the detailed tables, graphs and charts. We also publish a summary document **FES in 5** and our **FAQs**. For more information and to view each of these documents visit our website: www.fes.nationalgrid.com

As our modelling continues to evolve we will update this document to reflect those changes, ensuring our latest methods, models and techniques are shared. As with our other FES documents we welcome your feedback, please contact us at: transmission.ukfes@nationalgrid.com

Contents

Energy demand

This section describes the methods used to model energy demand. Energy demand modelling is split into five components:

1. Electricity Demand
2. Gas Demand
3. Industrial and Commercial Demand
4. Residential Demand
5. Transport Demand

Electricity demand

In FES we consider underlying demand. That is end consumer demand, regardless of where (transmission, distribution or on site) the electricity is generated, plus network losses. Demand is weather-corrected to seasonal normal for annual and average cold spell (ACS[1]) for peak. For clarity it does not include exports, station demand, pumping station demand or other forms of storage demand. When we illustrate residential, industrial and commercial components we have not assigned the distribution or transmission losses. We estimate these losses at the system level to average around eight per cent.

Peak demand is the maximum demand on the system in any given financial year. In order to make long-term ACS peak projections from annual demand we apply a recent historical relationship of annual to peak demand. For the residential sector there is a further adjustment using background data from the household electricity survey[2]. This creates an initial peak demand, to which we add components that history cannot predict, such as EVs, heat pumps and time of use tariffs (TOUTs).

Gas demand

The annual gas demand is defined as the total Local Distribution Zone (LDZ) consumption, plus the consumption at sites that are directly connected to the National Transmission System (NTS). Total GB annual gas demand includes gas exported to Ireland via the Moffat interconnector and exports to the continent via Interconnector UK. In the Energy Demand section of the FES document, demand only refers to underlying GB demand (excluding interconnector exports) whereas in the Supply section gas supplies are matched to total annual gas demand (including interconnector exports). Losses, and gas used for operating the system, (commonly referred to as Shrinkage) are included at the total system level. All values are weather-corrected where appropriate to ensure we don't allow more extreme weather to skew the results. Peak gas demand is calculated for a 1-in-20 day, as described in our Gas Demand Forecasting Methodology[3].

Total underlying GB gas demand is put together by modelling the following individual gas demand components: residential, commercial, industrial, transport and gas for power generation. These components are separated into demand which is connected at distribution and transmission level.

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[1] https://www.emrdeliverybody.com/Lists/Latest%20News/AllItems.aspx?&&p_Created=20161115%2011%3a17%3a12&&PageFirstRow=1&FilterField1=Category&FilterValue1=CM&&&View={C0855C66-F67D-4D84-9C26-CD4CAE25D06A}&InitialTabId=Ribbon%2ERead&VisibilityContext=WSSTabPersistence – under "Electricity capacity Report 2017"

[2] Cambridge Architectural Research, HES 24-Hour Chooser, 28 April, 2016, https://www.hightail.com/download/ZUczYkJrQXA1R01pR01UQwFuture

[3] National Grid, Gas Demand Forecasting Methodology, November 2016, http://www2.nationalgrid.com/uk/industry-information/gas-transmission-operational-data/supporting-information/

For the Two Degrees scenario we also model the gas demand required for the conversion to hydrogen.

Exports to Ireland and continental Europe as well as NTS and LDZ shrinkage are added to underlying GB demand for gas supply matching purposes. The scenario forecasts for Irish exports are based on Gas Network Ireland's Network Development Plan 2016[4] covering the next 10 year period. To cover the period from then until 2050, regression analysis is undertaken.

Gas demand for power station generation is derived from the pan-European Bid3 generation dispatch tool which produces an hourly dispatch for the GB electricity system.

Industrial and commercial demand

Industrial and commercial demand includes the demand of offices, shops, hotels, agriculture, ports, airports, manufacturing, power generation and grid scale storage.

Four economic scenarios comprised of 24 sub-sectors, and three retail energy price cases from Oxford Economics were used to create energy demand for industrial and commercial sectors.

The model examines 24 sub-sectors and their individual energy demands, giving a detailed view of GB demand, and uses an error-correcting model to produce projections for each sub-sector individually. The model then has two further modules to investigate the economics of increasing energy efficiency e.g. heat recovery, new technologies such as onsite generation e.g. combined heat and power (CHP), and different heating solutions e.g. air-sourced heat pumps.

These modules consider the economics of installing particular technologies from the capital costs, ongoing maintenance costs, fuel costs and incentives. These are used along with macro-financial indicators such as gearing ratios and internal rate of return (IRR) for each sub-sector to consider if the investment is economical and the likely uptake rates of any particular technology or initiative. This allows us to adjust the relative costs and benefits to see what is required to encourage uptake of alternative heating solutions and understand the impact of prices on onsite generation, which give our scenarios a wider range.

Industrial and commercial electricity demand side response (DSR)

We have made an assessment of the potential for what DSR could offer to this sector. This assessment was derived from a literature review of DSR potential and used to build our scenario ranges – alongside available data on DSR services from the Capacity Market and balancing services provision. We analysed the current development of new technologies and trends and looked at the factors that may impact on engagement by businesses in maximising DSR potential.

We started with a hypothesis that the nature of an individual business could limit its DSR participation; power demand profiles of different business sectors have clear signatures. Businesses' engagement with DSR is unlikely to reach its full potential in helping to balance the grid without access to appropriate volume and price data. We assume that the deployment of smart Information and Communication Technologies (ICT), and the development of innovative pricing schemes, will influence the levels of DSR.

[4] https://www.gasnetworks.ie/corporate/company/our-network/GNI_NetworkDevPlan_2016.pdf

Adopting ICT will create the potential for the reduction of energy consumption by end users and optimal operation of future smart grids. DSR promoting programs, smart pricing and ICT will not be able to significantly influence DSR individually. The presence of all three approaches will be needed to facilitate engagement in DSR within the industrial and commercial sectors. We anticipated a number of DSR activities as precursors to our modelling assumptions:

- Triad avoidance actions
- Capacity Market auctions
- Non-BM Balancing services (STOR and Frequency Response)
- TOUTs and new smart pricing schemes
- Information and Communication Technologies

Residential demand

The component parts we use to model residential energy demand are: appliances, lighting, heating technologies, insulation and home energy management systems.

Our base housing and population assumptions, developed from analysis from Oxford Economics, are consistent across our modelling scenarios. We assume that the population of GB reaches 74.7 million and that the number of homes grows to 31.5 million by 2050 in all of our scenarios. These compare to a population of 65.7 million and 27.8 million homes today.

We create residential electricity demand using a bottom-up method and deterministic scenario modelling. For each component part we use historical data, where available, as our starting point. The main source is the department of Business Energy and Industrial Strategy's (BEIS) Energy Consumption in the UK[5]. We also gather information on mobile phones, tablets and wi-fi routers from Ofcom's Communications Market Reports.[6]

From this point, we create projections using a selection of historic assessments; household projection data provided by external consultants; outcomes from reported external projects; regression analysis; deterministic and econometric methods. We benchmark these against stakeholder feedback and trial outcomes. We adjust each projection with our scenarios' assumptions to create the final results for each component.

For residential gas demand, we use the outcomes of our heating technology model, which creates projections of a variety of heating technologies:

- Gas boilers
- Heat pumps, including air source, hybrid, ground source and gas
- Fuel cells
- Micro-combined heat and power (mCHP)
- Biomass boilers
- Electrical Resistive Heating

[5] DECC, Energy Consumption in the UK, April 2016, https://www.gov.uk/government/collections/energy-consumption-in-the-uk
[6] https://www.ofcom.org.uk/research-and-data/multi-sector-research/cmr

- Oil boilers

The model takes into account housing size and energy needs as well as additional economic and social factors. This is combined with a whole-house energy efficiency model which looks at the change in space heating energy consumption per house. It is then further refined by our home energy management system model by accounting for additional energy savings to then reach the final residential gas demand.

Residential electricity DSR

Our DSR scenarios are built on an assumption that DSR's effect on reducing peak demand relies on a combination of smart appliance and smart meter take-up and the presence of smart pricing in the market. The engagement levels will grow as participation with smart technology develops.

Consumer Engagement: We have applied the four consumer engagement segments that were initially published by Ofgem in 2014 and updated in 2016[7] to the four FES scenarios. We made a hypothesis that consumers will become educated and engaged in efficient energy use through marketing programmes and general development of smart technologies. Engagement levels are applied to each market segment individually based upon the **Scenario Framework**. This engagement level will change over time in response to both technology development and changes in attitude regarding energy use.

Smart Meters: Our scenarios use latest BEIS and Ofgem information as a reference. This is in terms of current installation results as well Ofgem's future projections for our Two Degrees scenario. However our other scenarios provide a range which extends beyond these projections based on historic installation rates.

Smart appliances: Adoption of appliances with smart performance control is benchmarked based on global sales data. It is assumed that adoption of wifi-enabled appliances grows over time at different rates in the four scenarios based on customers' engagement levels. Despite the adoption of smart appliances, the decrease in peak demand is delayed as it follows learning and adaptation curves i.e. the appliances once purchased are not utilised to their full potential straightaway.

TOUTs: We have made a number of assumptions regarding the rate at which Time-Of-Use-Tariffs (TOUTs) are developed and also regarding the percentage of people who are engaged in changing their electricity consumption pattern as a result. It is assumed that over time a broader range of TOUTs will be presented to the market in the more innovative scenarios leading to higher levels of DSR.

Transport demand electric vehicles (domestic)

The Electric Vehicle (EV) model, including both Pure Electric and Hybrid Electric vehicles, utilises multiple strands to produce the annual electricity demand.

To model the uptake of domestic electric vehicles we made a number of assumptions on the uptake rates for different scenarios; for example to meet transport targets for Two Degrees 100% of domestic vehicles must be electric by 2050. These uptake rates for the different scenarios, in relation to the

7 https://www.ofgem.gov.uk/system/files/docs/2016/08/consumer_engagement_in_the_energy_market_since_the_retail_market_review_-_2016_survey_findings.pdf

expected sales projections for all vehicles (determined by looking at previous annual sales) and the rate of which older vehicles are scrapped, gives the expected number of electric vehicles on the road. The number of miles driven per year, determined from previous average mileage and current trends, along with the propulsion ratio (kWh/Mile), produces the kWh/year of the domestic electric vehicle fleet.

The influence of autonomous vehicles (level 4 automation[8]) has been included within the scenarios this year based upon stakeholder feedback; and where they are shared vehicles this has influenced the number of other cars they displace.

Following stakeholder feedback on the available domestic charger sizes we have increased the charger size from 3.5kW to 7kW for all new vehicles, which influences the peak and summer minimum demand values. This is mitigated by improved data on the diversity of peak time charging and the impact of smart charging. Varying degrees of smart charging have been assumed for all future years.

Natural gas and hydrogen vehicles

Gas demand from Natural Gas Vehicles (NGVs) is modelled in a very similar way to electric vehicles. Gas demand is determined from previous average mileage and current trends, along with the propulsion ratio (kWh/Mile) for different sizes of Heavy Goods Vehicles. The model looks at demand for both compressed natural gas (CNG) and liquefied natural gas (LNG). This year we have included the use of hydrogen for transport within our modelling. We have used the RESOM model (covered in more detail in the Annex) to determine the volume of hydrogen and the amount of gas required to produce this hydrogen.

[8] https://www.sae.org/misc/pdfs/automated_driving.pdf

Electricity supply

Electricity supply components include electricity generation installed capacity, electricity generation outputs, interconnectors and storage. Our scenarios consider all sources and sizes of generation, irrespective of where and how they are connected; from large generators connected to the National Electricity Transmission System (NETS), medium-size industrial and commercial generation connected at the distribution level, through to small-scale, sub-1 MW generation connected directly to commercial premises or domestic residences throughout GB.

In addition, in all scenarios there is enough supply to meet demand. For electricity this means meeting the reliability standard as prescribed by the Secretary of State for Business, Energy and Industrial Strategy – currently three hours per year loss of load expectation (LoLE). See annex for more details on how LoLE is calculated.

Out to 2020, our analysis is largely driven by market intelligence, including the Transmission Entry Capacity (TEC) Register[9], Embedded Register[10] and data from procured from third parties. Between 2020 and 2030, there is a mixture of market intelligence and assumptions, with assumptions playing an increasing part towards the end of the decade. After 2030, there is very little market intelligence available so we rely more on our assumptions. These can be accessed in the **Scenario Framework** document.

Electricity supply transmission installed capacities

The electricity supply transmission installed capacities uses a rule based deterministic approach. An individual assessment of each power station (at a unit level where appropriate) is completed, taking into account a wide spectrum of information, analysis and intelligence from various sources.

The scenario narratives provide the uncertainty envelope that determines the emphasis placed on the different types of generation technology within each scenario. Each power station is placed accordingly within their technology stack in the merit order it will be used.

The placement of a power station is determined by a number of factors, such as market intelligence, energy policy and legislation. Project status and economics, which are applicable to that particular power station, are also taken into account. The contracted installed capacity or TEC Register provides the starting point for the analysis of power stations which require access to the National Electricity Transmission System (NETS). It provides a list of power stations which are using, or planning to make use of, the NETS. Although the contracted installed capacity provides the basis for the majority of the entries into the generation installed capacity, the analysis is not limited to generators with a signed connection agreement. Other projects where information has been received in the very early phases of scoping (i.e. pre connection agreement) are also taken into account.

Electricity supply distribution installed capacities

Our distributed generation installed capacities include those non-transmission sites that are greater than 1MW and are typically connected to one of the 13 distribution networks. We also include sites

[9] http://www2.nationalgrid.com/UK/Services/Electricity-connections/Industry-products/TEC-Register/
[10] http://www2.nationalgrid.com/UK/Services/Electricity-connections/Industry-products/Embedded-Generation-Register/

that are less than 1MW ("micro generation") and the smallest of these sites may be connected directly to properties behind the meter (e.g. rooftop solar).

For the sites greater than 1MW we consider 30 technologies covering both renewable and thermal generation:

Gas CHP	Waste CHP	Fuel Oil	Landfill Gas	Wind Onshore
Advanced Conversion Technology (ACT) CHP	Onsite Generation	Advanced Conversion Technology (ACT)	Sewage	Wind Offshore
Anaerobic Digestion CHP	CCGT	Anaerobic Digestion	Tidal	Battery
Biomass CHP	OCGT	Biomass - Co Firing	Waste	Compressed Air
Geothermal CHP	Diesel Reciprocating Engines	Biomass - Dedicated	Wave	Liquid Air
Sewage CHP	Gas Reciprocating Engines	Hydro	Solar	Pumped Hydro

To determine the current volumes of renewable generation we obtain data from various sources including the Ofgem Feed In Tariffs (FiT) register[11] and the Renewable Energy Planning Database[12]. For thermal generation we use the Combined Heat and Power Quality Assurance (CHPQA) register[13] and the Capacity Market register. The projections per technology capacity are based on growth rates that reflect historical trends and any changes in the market conditions. Where available, growth of known future projects is used.

For those sites less than 1MW, including generation at residential level, we consider ten technologies:

Biogas CHP	mCHP	Gas CHP	Hydro	Solar
Biomass CHP	Anaerobic Digestion	Battery	Fuel Cell	Wind

Baseline data, from Renewable Obligation Certification Scheme and Feed in Tariff data, at GB level per technology has been used to determine the starting point and historical trends have been used to project the deployment of sub 1MW generation in the future.

Electricity generation output

In FES 2017, we have calculated power generation output using a model called Bid3, which is a pan-European electricity dispatch model capable of simulating the electricity market in Great Britain and other countries. This is the first time we have used this model for FES generation analysis.

The model uses the FES 2017 generation installed capacities and demand assumptions as inputs. This includes all of our capacity assumptions, annual demands and fuel prices. The simulations are

[11] https://www.ofgem.gov.uk/environmental-programmes/fit/electricity-suppliers/fit-licensees
[12] https://www.gov.uk/government/collections/renewable-energy-planning-data
[13] https://www.gov.uk/guidance/combined-heat-power-quality-assurance-programme

based on end-user consumption meaning that generation connected to both transmission and distribution networks are considered as supply.

Bid3 works by seeking to find the optimised way to meet demand using available generation, based on minimising total cost. It can analyse the impact of different weather conditions using profiles based on historic actual demand. The electricity generation output modelling for FES 2017 has been based on the historic year of 2012 as this was deemed to be a fairly average year with colder and milder spells. Bid3 creates an hourly time series of demand using the annual value from FES and the relevant historic hourly profile according to:

Bid3 hourly demand = FES annual demand / (24 * 365 * hourly profile value)

All electricity generation has been modelled with an average availability to allow for maintenance and forced outages. This varies on a monthly basis to allow for seasonal variations. The electricity generation output was calculated by modelling GB only. The outputs from the dispatch model were used to produce the FES power generation outputs for different generation technologies. In addition, the outputs from Combined Cycle Gas Turbines (CCGTs) were used as an input for the gas demand modelling.

Electricity interconnector capacities

We have further developed our analysis methods over the past year based on stakeholder feedback.
We identify potential projects and their expected commissioning dates to connect to GB. This information is from a range of sources including the electricity European Network of Transmission System Operators (ENTSO-e) ten-year network development plan[14], 4C Offshore[15] and the European Commission[16]. Where only a commissioning year is given we assume the date to be 1 October of that year.

We assess each project individually against political, economic, social and technological factors to determine which interconnector projects would be built under each scenario. If it does not meet the minimum criteria we assume it will not be delivered in the given scenario, or that it will be subject to a commissioning delay. We calculate this delay using a generic accelerated High Voltage Direct Current (HVDC) project timeline. All projects which have reached final sanction are delivered, though they may be subject to delays in some scenarios.

In all the scenarios we assume that the supply chain has enough capacity to deliver all interconnector projects. While we analyse individual projects, we anonymise the data by showing only the total capacity per year, due to commercial sensitivities.

Electricity interconnector annual and peak flows

For FES 2017, we used Bid3 to model all markets that can impact interconnector flows to GB for our four scenarios. We modelled all future years until 2050 and calculated both annual flows and flows we might expect at winter peak. We modelled each future year five times to look at the impact of different weather conditions based on those we experienced from 2009 – 2013. These five recent years

[14] ENTSO-e, Ten-Year Network Development Plan 2016, https://www.entsoe.eu/major-projects/ten-year-network-development-plan/ten%20year%20network%20development%20plan%202016/Pages/default.aspx
[15] 4C Offshore, Offshore Interconnectors, http://www.4coffshore.com/windfarms/interconnectors.aspx
[16] European Commission, Projects of Common Interest candidates for electricity, https://ec.europa.eu/energy/sites/ener/files/documents/pci_candidates_for_electricity.pdf

provided a good mix of cold and milder spells for our analysis. This also ensured we considered a range of conditions in neighbouring markets, which is particularly important for peak times. The values that we present in FES are averages taken over the full five-year period. For further information on how interconnectors are modelled see the Electricity Capacity Report[17]

Electricity storage

The electricity storage technologies which have been included in our scenarios this year are the same as those in FES 2016:

- Various battery technologies
- Pumped hydroelectricity storage (PHES)
- Compressed air electricity storage (CAES)
- Liquid air electricity storage (LAES)

As some electricity storage technologies at large scale are new such as lithium-ion batteries, there is limited data available for modelling and analysis. We have examined recent storage trials as well as those currently underway or under development to gather data on the potential of storage. Additionally we have benchmarked and considered other external projections, such as those by Poyry and Imperial College London. To create a range of outcomes we have examined the current deployment of storage technologies, the potential revenue streams available, as well as pairing storage with renewable technologies such as wind and solar PV. From this we have created a range of transmission and distribution connected technologies.

We utilised an economic dispatch model to examine the usage of storage on the system to determine the potential utilisation under the generation mix for each scenario and year.

[17] https://www.emrdeliverybody.com/Lists/Latest%20News/Attachments/116/Electricity%20Capacity%20Report%202017.pdf

Gas supply

In FES we consider Gas Supply which enters the National Transmission System (NTS) and the Distribution Networks (DN). Total gas supply is derived from different gas supply elements that are spoken about in more detail below. The models we use are supported by market intelligence, historical data and assumptions that we developed from knowledge gathered from both internal and external stakeholders.

The supply ranges for the different gas supply types are derived before being matched to the gas demand for each scenario. The **Scenario Framework** drives the level of each supply type based on political, economic, social and technological and environmental factors. Then they are applied to each scenario in order to meet demand.

UK continental shelf (UKCS)

The UKCS is the name given to the sea bed surrounding the United Kingdom. From this region gas producers extract natural gas which is sent to the UK. The scenarios are derived using a mixture of gas producers' future projections which are gathered through an annual questionnaire process as well as stakeholder feedback gathered during our stakeholder consultation period. We create ranges to be used within each of the scenarios by making adjustments to future field developments based on historic production and the economic and political conditions as laid out in the **Scenario Framework**.

Norwegian supplies

Norwegian gas comes from the Norwegian continental shelf, usually divided in to the North Sea, the Norwegian Sea and the Barents Sea and is exported to countries, including the UK. The Norwegian flows to the UK are calculated by creating a total production range for existing and future Norwegian fields. Our primary data source is the Norwegian Petroleum Directorate[18]. The range is derived by making separate assumptions for future field development based on historic production and the future economics. For example in the high range we assume a high level of production in the Barents Sea, whereas in the low range we have no production from this area. Once we have created a production range we then calculate how much will come to the UK, with a mixture of historic flows and existing contracts. Finally we test our projections with industry experts to ensure our projections are credible.

Shale gas

Shale gas is natural gas occurring within or extracted from shale. No UK shale gas production information is currently available. Due to this we believe that the Institute of Directors (IoD) Report[19] from 2013 remains the best source on which to base our projections. This report assesses the potential GB shale gas production from 100 onshore drilling sites (pads) based on the flow rates experienced from the US shale gas industry. Our high range is based on a 50 % success rate from the IoD report while the medium case is based on a 25% success rate. The low range will remain zero until test wells prove the commercial and technical viability of UK shale.

[18] http://www.npd.no/en/
[19] https://www.igasplc.com/media/3067/iod-getting-shale-gas-working-main-report.pdf

Biomethane

Biomethane is a naturally occurring gas that is generated from anaerobic digestion (AD). AD is a biological process where microorganisms break down organic matter such as sewage, plant material and food waste in the absence of oxygen to produce biomethane. The biomethane range for FES 2017 is derived using the latest information available from biomethane sites currently connected to a gas network, and the DN's latest information on possible future connections. To derive the high and low case we apply different growth rates and assumptions to new connections due to the differing economic and political conditions within each scenario. To support our outputs we use market intelligence and test our results with relevant industry experts.

Bio substitute natural gas (BioSNG)

BioSNG is a gas that is derived from household waste. The process uses high temperatures to produce a synthetic gas which, after cleaning and refining, can be injected into a natural gas network. BioSNG is in the early stages of testing with a commercial demonstration plant planned for operation in 2018. The supply range is based upon the flow information published in the Network Innovation Competition[20] documentation plus assumptions on the number of facilities, based upon the economic and political conditions for each scenario.

Liquefied natural gas (LNG)

LNG is traded in a global market connecting LNG producers to natural gas users. The deliveries of LNG are therefore subject to market forces such as the arbitrage between global market prices and particular weather spikes driving a change in gas demand. We assume that a minimum level of LNG will always be delivered to the GB market, and our assessment of this is based on historic levels. These levels are flexed based on the volume of GB gas demand and indigenous supply.

Continental interconnector imports.

Our interconnectors are Interconnector UK (IUK) and Balgzand Bacton Line (BBL) and both connect to the UK at the Bacton terminal. IUK connects to Zeebrugge in Belgium and BBL connects at Balgzand in the Netherlands. For future continental interconnector imports we have used the minimum imports observed over the last decade

Generic imports

The generic import is a volume of gas that is required in order to meet the remaining annual demand after other sources have been utilised. This gas can be made up of either LNG imports or Continental interconnector imports.

Annual supply match

The primary function of the supply match is to match supply to demand on an annual basis. To do this we apply the supply sources in a ranking order. As indigenous gas production (UKCS, shale and green gas) is ranked highest because it is all UK based and will have large domestic supply chain investments in place, we apply these to our supply match first. Following this we apply the Norwegian

[20] https://www.ofgem.gov.uk/network-regulation-riio-model/network-innovation/electricity-network-innovation-competition

imports, the levels of which are driven by the **Scenario Framework**; then minimum levels of LNG and continental gas imports are added. Finally a supply/demand match is achieved by applying generic import, which as mentioned above can be made up of either LNG or continental pipeline gas

Peak gas supply

The purpose of a peak match is to ensure current domestic production and import infrastructure can meet a peak demand day. For indigenous gas production (UKCS and shale) there is a 20% difference between maximum and minimum production levels across the seasons applied. This is based on observed values from offshore UKCS production. For onshore shale gas there is insufficient data to derive a likely difference between maximum and minimum. As these sources are likely to be base load, but with outages for maintenance, the UKCS difference between maximum and minimum was seen as the most appropriate to use.

For imported gas and storage, the design capability of the import facility is used to determine the capacity. This may differ from the approach in shorter-term documents, such as the Winter Outlook, which are based on near-term operational expectations.

The total of these supplies are then matched to the peak demands to calculate the margin of supply over demand. We also carry out security of supply analysis where we remove a large piece of import infrastructure from the supply mix and again calculate the margin of supply over demand; this is referred to as an N-1 assessment[21].

[21] https://www.gov.uk/government/publications/uk-risk-assessment-on-security-of-gas-supply-2016

Annex - Modelling carbon reduction target

For our **Two Degrees** scenario and three of our sensitivities which achieve the carbon reduction target, we use a cost-optimisation model RESOM to guide them towards the target. During the process of meeting the carbon reduction target, RESOM selects the least-cost solution among all the possible sector and technology developments, through calculating all cost components including capital cost, fixed and variable operational cost, as well as product costs, transferring future costs into present value using discount factor.

RESOM simulates the whole energy system, considering energy demand, supply, electricity and gas network and interconnectors. On the demand side, it shows the specific demand profile for different products in residential, commercial and industrial sectors, as well as various vehicle types in transport sector. Efficiency factors for different products in all future years are included. The finest granularity in RESOM is 4 hours, to capture the within day demand change, and it also contains the information of seasonal demand shape.

On the generation side, it considers gas supply and electricity generation from different sources and different technologies. Existing capacities and load factors are available for each technology, and operational cost information is also included, which ensures that generation types with the lowest operational cost, such as renewables, are supplied first to meet demand. For future development, minimum and maximum capacities constraints as well as growth rate constraints are set up, to make sure all the developments are within realistic ranges.

Overall, approximately 5,000 constraints are used for each model run, to ensure energy flow is within network capacity, supply meets demand, and the whole system is balanced on an annual, seasonal, and daily peak basis. Given different assumptions for particular technology development, different scenarios and sensitivities that meet 2050 carbon reduction target at lowest cost can be generated.

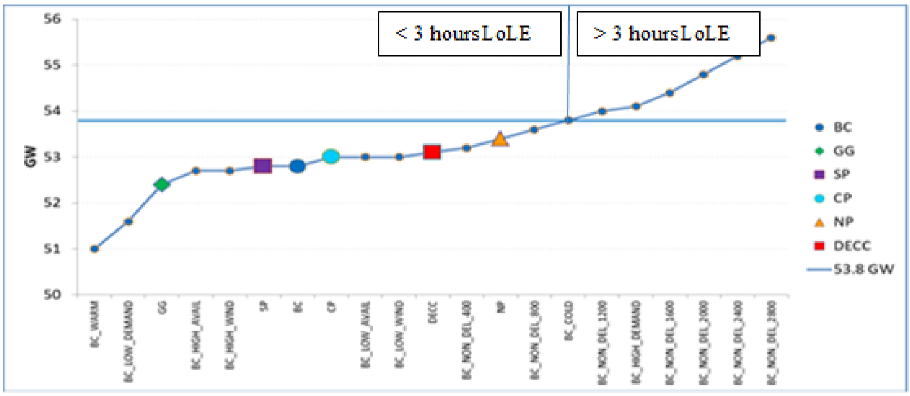
The model inputs and constraints are evaluated against external benchmarks from UK experts in 2050 energy modelling. These include University College London, the Committee on Climate Change, the Energy Technologies Institute and the Energy Research Partnership.

Annex – Electricity security of Supply

The 2017 FES generation backgrounds have been developed to reflect the particular scenario assumptions, the latest market information and to target the GB Reliability Standard of 3 hours LoLE/year. In doing so the backgrounds reflect the latest market signals, the Capacity Market (CM) auction results and thereafter the capacity calculated to meet the Reliability Standard.

Although the Reliability Standard is set at 3 hours LoLE the recommended capacity to procure in the CM auctions is not based on one scenario of the future but addresses the inherent uncertainty by considering a range of alternative scenarios of the future.

This can best be illustrated by the following chart of the alternative scenarios and sensitivities considered for the 2017/18 Early Auction (EA) (x-axis) and the level of capacity required to meet the Reliability Standard (y-axis). It shows the four FES scenarios, Base Case, DECC scenario and the sensitivities around the Base Case.



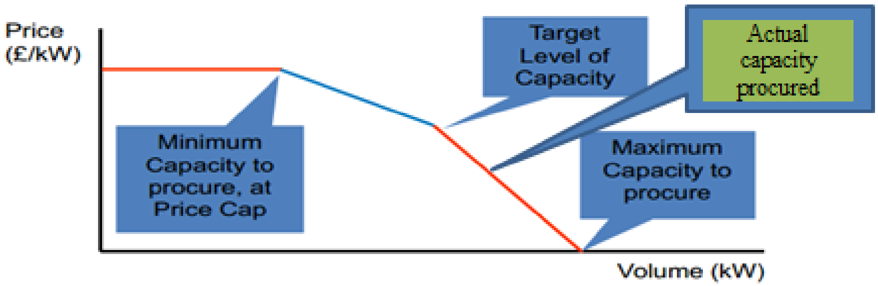
Source: 2016 Electricity Capacity Report – 17/18 EA (National Grid)

The process for determining the capacity to procure is known as Least Worst Regret (LWR) and is a cost optimisation of the potential outcomes to ensure the consumer receives the best value for money. It does this by assuming costs consistent with the Reliability Standard (~£49/kW for capacity and £17,000/MWh for loss of load) and then calculates for all combinations (excluding the DECC scenario) the least worst cost if a scenario or sensitivity is assumed and another one occurs.

As the cost associated with LoLE is a non-linear function then it will almost certainly recommend a higher capacity than the Base Case, as for the EA above, which shows the cost optimised results (solid blue line) being higher than the Base Case (dark blue dot). This is because LoLE increases exponentially as margins become tighter whereas capacity costs increase linearly i.e. 1GW will always cost £49/kW while LoLE per GW of capacity will increase as margins tighten and will cost more even though the unit cost is unchanged at £17,000/MWh.

This therefore means that the CM auction will target a capacity higher than the Base Case requirement resulting in a higher capacity being procured and therefore higher margin and lower LoLE then 3 hours for the Base Case. This can be illustrated in the above chart where all the scenarios and sensitivities (including the Base Case) below the target capacity will have less than 3 hours LoLE and for all the scenarios and sensitivities above the target capacity will have more than 3 hours LoLE. This confirms why the later years (beyond the auctions) in the FES scenarios are closer to 2 hours LoLE for all scenarios as they have capacity requirements lower than the target capacity i.e. to the left of the vertical blue line.

In addition to the target capacity being higher than the Base Case requirement to meet 3 hours LoLE the actual capacity procured in the auction can be higher again. This is due to the sloping nature of the Demand Curve (see below) that allows procurement up to ±1.5GW either side of the targeted capacity depending on whether the auction clears at a price below or above the capacity cost assumed (£49/kW). So far all auctions (EA and 18/19, 19/20 & 20/21 T-4) have cleared at a low price and have therefore resulted in more capacity than targeted being procured. This increases the capacity and further reduces the LoLE for the Base Case in the early years although adjustments made to the T-1 auction target capacity should limit this increase.



Source: EMR Delivery Body Portal – Demand Curve (National Grid)

The previous two explanations cover the theoretical implementation of the Reliability Standard and the auction delivering additional capacity over the medium term. There is also another more practical reason which relates to what the market outside the CM has delivered e.g. unsuccessful plants in the auction deciding to stay open and thus increasing the margin over the short term and further reducing the LoLE.

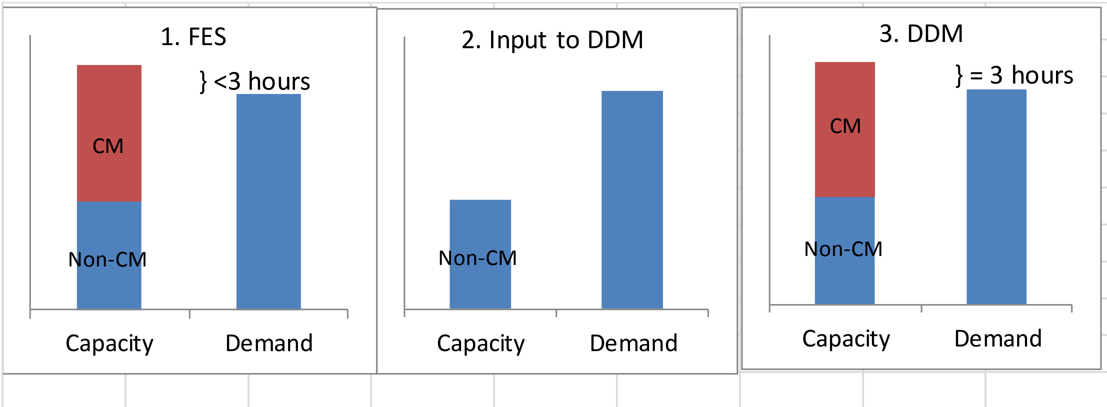
The final element is a technical and/or timing one around wind EFC (Equivalent Firm Capacity) which in the FES scenarios are based on a proxy from the previous year's probabilistic modelling which can lead to an over / under estimate of EFC (when margins are higher / lower when compared to the previous year) which isn't updated until the following year as the probabilistic modelling is undertaken after the deterministic FES modelling is completed.

In conclusion the FES generation backgrounds will all target initially what the market has delivered post CM auctions resulting in the early years a LoLE closer to 1 hour; however, thereafter LoLE is closer to 2 hours to reflect the agreed methodology for calculating the target capacity for the CM auctions. The only way the FES scenarios could target 3 hours is if the uncertainty in the future becomes significantly less and the range of the scenarios and sensitivities becomes very narrow resulting in the LWR target capacity being close the Base Case; however, this doesn't appear a realistic assumption for a number of years.

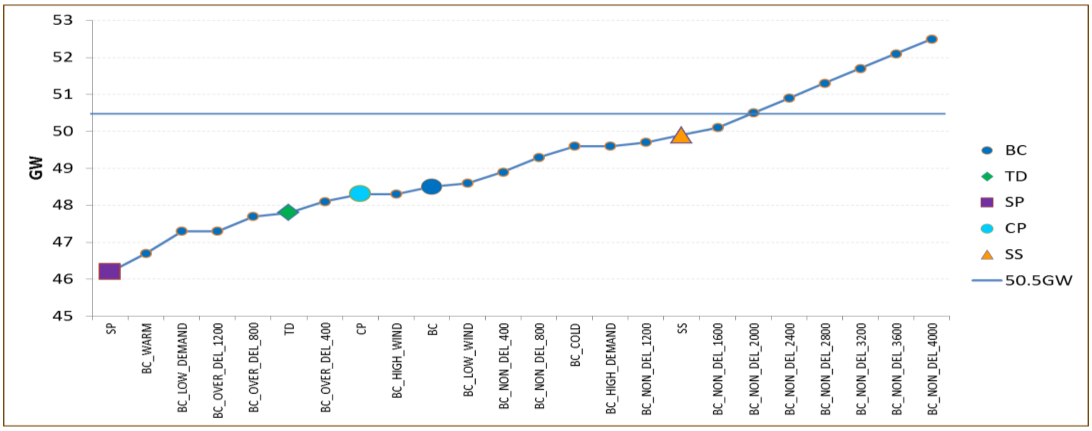
Annex – LoLE step by step guide

This annex illustrates why the theoretical implementation of the GB Reliability Standard leads to a CM Base Case with LoLE <3 hours (steps 1 to 7) and then the market delivers a LoLE lower than that (steps 7-1) but can still be said to target the market implementation of the Reliability Standard. This process can be summarised into 9 steps:

1. FES scenarios plus Base Case have <3 hours LoLE
2. Input into DDM Non-CM capacity for a scenario along with the demand
3. DDM run to give CM capacity required to give 3 hours LoLE



4. Repeat 1 to 3 for all scenarios and sensitivities
5. Input all scenarios and sensitivities (all = 3 hours LoLE) into LWR tool
6. Run LWR tool to give cost optimal answer



7. Resulting capacity(50.5GW) > Base Case (48.5GW) hence Base Case <3 hours LoLE
8. Auctions result so far have delivered low prices and more capacity has been procured resulting in Base Case <2 hours LoLE for the period of the auctions (note Sec of State adjustments to Demand Curve can increase the capacity targeted and reduce LoLE still further e.g. 20/21)
9. Update auction results for known developments e.g. unsuccessful CM plant remaining open, higher availabilities etc. which result in the Base Case and FES scenarios with LoLE initially <1 hour LoLE thereafter within range of 0.5 to 2.5 hours LoLE which then returns you to step 1.

Note, virtually all electricity markets around the world deliver more capacity than required to meet their Reliability Standard some significantly more e.g. Netherlands and Ireland.

Version

Version number	Date of update	Description of update
1.0	13/07/17	First upload for FES 2017 launch on 13th July 2017

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