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Introduction to energy system flexibility

What is flexibility and why do energy systems need it?

Every year National Grid Electricity System Operator (ESO) produces the Future Energy Scenarios (FES). These scenarios look at the uncertainty of the future of energy; including the challenge of meeting net zero and the impact of this on future energy supply and demand.

Archie Corliss, one of the ESO's Strategic Insight Leads, introduces energy system flexibility, a concept which is explored in more detail in FES 2020 as it will play a vital role in decarbonising energy supply and helping to meet the UK's net zero target.

What is flexibility?

Energy systems need to continuously match supply to demand, we call this energy balancing. Energy system flexibility is the ability to adjust supply and demand to achieve that energy balance. It also allows us to keep the flows of energy through the networks within safe limits; but that is beyond the scope of FES[1].

To deliver energy from where it is supplied or generated to where it is needed it must be transported in some way. This can be across national systems like the electricity or gas networks or in tankers moving fuels such as petrol around the country. Both supply of and demand for energy flowing through networks vary, and these fluctuations are difficult to forecast perfectly, meaning that at times they will be out of balance.

Energy demand varies for several reasons, including seasonal and within day variations with temperature and weather conditions, long-term energy efficiency trends, and the impact of short-term spikes in the price of commodities, or as we have seen in 2020, a global pandemic. Energy supplies vary due to the availability of renewable energy generation, the supply of energy from the UK's North Sea gas fields, and the arrival of imports of other fuels such as oil, coal and natural gas.

Other factors can also cause mismatches in supply and demand, such as generation outages, network constraints or forecasting errors. Flexibility helps ensure that supply and demand match second by second – 24 hours a day and 365 days per year.

To meet net zero carbon emissions, flexibility will become more important due to factors such as such as growth in levels of renewable generation, increasing electrification of heat and transport and changes in consumer behaviour. Electricity system flexibility has the greatest need for change due to the significantly increased demand we expect and the lower amount of spare capacity on the network at peak times.

What sort of flexibility do energy systems need?

All energy systems need to balance energy flows, but different systems can do this over different timescales due to their different levels of inherent storage and flexibility. Types of flexibility vary according to how much energy they can deliver, the length of time they can deliver this for and how quickly they can respond. The timescales for system balancing requirements can range from second by second for sudden surges in TV use or up to months at a time managing the differences in energy demand and supply between different seasons, for example higher gas network demands in winter.

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[1] FES models energy flows on unconstrained networks, the network impacts of these flows are analysed in other ESO and industry publications.

On the electricity system, generation always needs to match demand second by second to keep system frequency and voltage stable. We make sure there is sufficient generation capacity held in readiness to manage unplanned events and meet security of supply standards[2]. Flexibility at shorter timescales is referred to as stability and we manage this using a range of tools explored in our System Operability Framework.

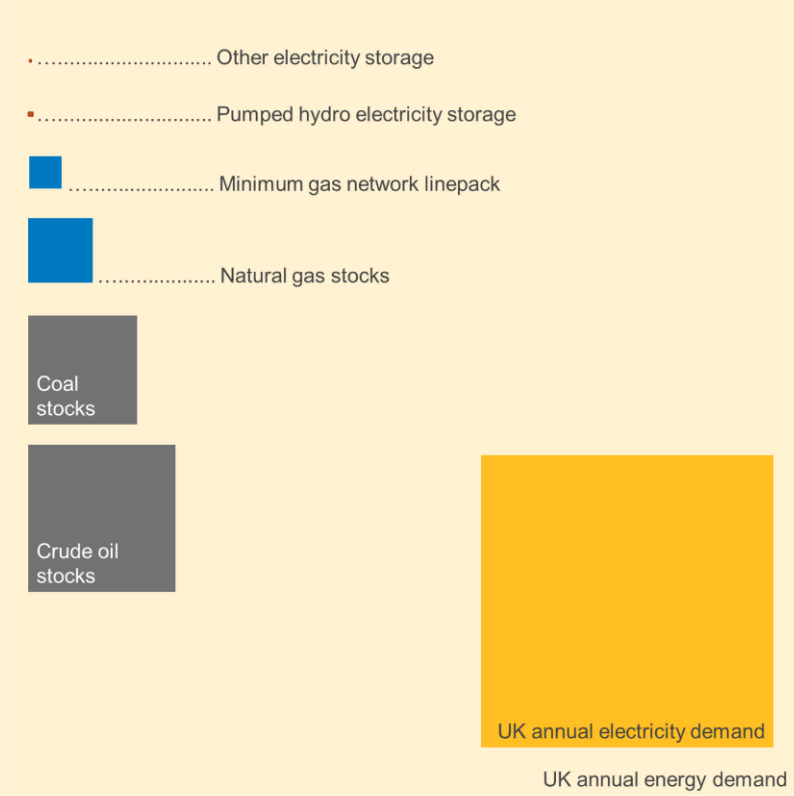
The gas system is less sensitive to short-term variations in supply and demand but must still meet security of supply standards[3]. It needs to balance every day but not second by second in the same way as electricity. Other energy sources such as petrol and coal vary over longer timescales according to the scale of local storage of fuel at locations like petrol stations and coal power stations.

Where can we get flexibility from?

Storage of gas in the gas network itself provides flexibility to the gas system. The amount of gas contained within the higher-pressure parts of Britain's gas network is known as 'linepack'. Linepack can be varied by changing the pressure of the gas and the range over which it can be varied is referred to as 'linepack flexibility'.

Linepack is proportional to the pressure of the gas in the pipelines. Higher pressure means more gas in the pipes and so more energy is stored. Linepack levels change throughout the day; when demand exceeds supply, levels of linepack decrease along with system pressures, and vice-versa when supply exceeds demand. This flexing of pressure helps match daily supply and demand for gas.

Scales of different types of energy storage (DUKES, 2018)



As well as the linepack in the pipes there is also additional storage provided by gas caverns and LNG storage connected to the pipelines. The UK has historically had high levels of gas storage capacity using depleted gas fields and salt caverns to store methane. In 2010 GB had around 45 TWh of gas storage, which had dropped to 15 TWh by the end of 2019, primarily due to the closure of the Rough offshore storage facility (32 TWh)[4]. The remaining sites are mainly used for short- and medium-term storage rather than interseasonal. There are also several gas interconnectors between GB and continental Europe, which typically import more gas in winter than in summer and allow GB to benefit from gas storage facilities in continental Europe, offsetting the reduction in our own gas storage levels. Other fossil fuels can be stored in tanks or stockpiles, this usually exceeds the energy in gas storage as seen in the figure above.

Storing electricity and discharging it back to the electricity system can provide additional flexibility. Electricity cannot be stored directly and instead needs to be converted to another form of energy to be stored for later use. It can be converted into mechanical potential energy in pumped hydro or compressed air storage, thermal energy in liquid air energy storage or electrochemical energy in batteries. Types of storage with different durations are used in varying ways. For example, short duration storage can be used over short periods to meet peak demands, manage periods of excess supply, or provide grid stability services. Longer duration storage can be used to balance the system over longer periods of high or low renewable generation and seasonal differences in demand.

Historically most flexibility has come from the supply side of the electricity system; by varying the amount of gas produced or imported, or by turning up or down electricity generation, such as gas turbines. This has played an increasingly important role on the electricity system in recent years as greater proportions of variable renewable

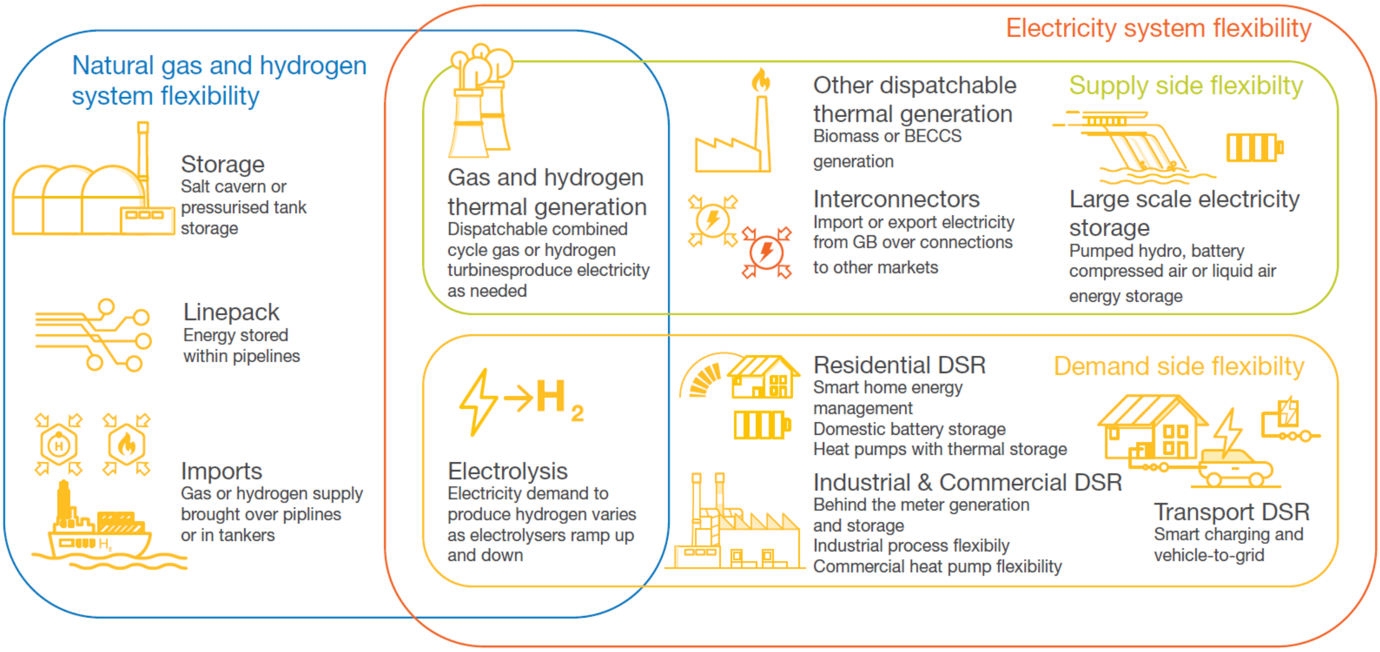
[2] The Security and Quality of Supply Standard (SQSS) sets out the reliability standard for the electricity system, currently three hours per year loss of load expectation (LOLE). For detailed definition, please refer to the Modelling Methods document.
[3] For gas, there is no direct equivalent to LOLE, however the N-1 condition is used as a guide. There must be enough supply to meet the peak demand on a very cold day (a 1-in-20 peak winter day), even if the single largest piece of supply infrastructure were to fail.
[4] https://www.ofgem.gov.uk/system/files/docs/2020/01/gas_storage_table_january_2020.pdf

generation have been introduced, and gas generation has been used to ramp up and down as renewable output changes.

Flexibility can also be provided by varying demand to help match supply; with consumers increasing or reducing demand or changing the time they consume energy, for example turning down an industrial process during peak times or charging electric vehicles at off peak times. This is increasingly relevant on the electricity system which needs to match supply and demand in the shortest timescales.

Demand side flexibility can be provided from any of the residential, industrial and commercial or transport sectors, and each has different characteristics and abilities to respond. The value to the system of most individual actions is low; however, aggregating large numbers of simultaneous consumer responses produces a significant effect. These actions need to be coordinated by bodies such as aggregators or energy suppliers who incentivise individual participants to provide flexibility and use a portfolio of demand side response (DSR) technologies and generation to deliver flexibility. As such, management of the large amounts of data involved also becomes increasingly important.

Types of networked energy system flexibility



How will net zero change the flexibility we need?

Increasing electrification of heat and transport moves energy from systems with high levels of inherent and stand-alone storage, such as the gas network and petrol forecourts, to the electricity system which has relatively lower levels of storage.

To meet net zero, renewable generation capacity will need to increase. This will lead to greater variability in generation output, increasing the need for flexibility to manage the differences between generation and demand.

The reduction in unabated fossil fuel generation to zero in 2050 removes a traditional source of supply-side flexibility. Some of this could be met by gas generation with carbon capture and storage, or from hydrogen generation, however the balance will need to be made up elsewhere. These changes are happening rapidly; the ESO has an ambition to operate a carbon-free electricity system by 2025.

Supplies of gas and electricity will move to different locations, changing the flexibility in networks moving energy. For example, the electricity system will have more distribution-connected generation, and higher levels of offshore wind, changing the operation of the electricity transmission system and its flexibility needs. As fossil fuel consumption reduces, sources of gas or hydrogen will relocate, with electrolysis often co-located with renewable generation or where it can provide most help to the system. This will require networks to move this energy from where it is produced to where it is needed.

The shift to net zero will also present opportunities for greater flexibility in some areas. We expect electricity demand to increase with greater electrification, and in a net zero world we expect increased consumer engagement, particularly in scenarios with higher levels of societal change. This presents an opportunity for greater levels of demand side flexibility.

How will markets need to change?

Energy markets are the primary tool for balancing supply and demand. They use price signals to adjust supply and demand so the system balances. When there is too little supply or too much demand the price on the wholesale market rises which stimulates supply to increase and demand to drop. However, current energy demand is very inflexible and much of it is shielded from price signals by flat tariffs, so most of the balancing is done by the supply side. The market does not balance perfectly so system operators are required as a residual balancer to make the final adjustments.

Under current electricity market arrangements, the wholesale price for each half hour is largely set based on the expected marginal cost of the generation required to meet the last unit of demand in that half hour. However, as renewables begin to make up more of the generation mix, they become the marginal generation far more often and as they all have almost zero marginal cost the market price collapses. If the market continues to operate in the same way, renewable generation could potentially be affected by price cannibalisation[5]. This can set a ceiling on the potential for wind and solar PV generation as beyond a certain installed capacity new generators would not be able to make sufficient returns to be financially viable. It may not be possible to reach the renewable generation capacities we forecast in our net zero scenarios without some form of market change or market interventions.

In our modelling, we assume that market participants make sufficient returns to encourage investment, so capacity will be installed smoothly as the system needs it. This is a simplification; in practice the system may need investment in technology before that technology can make a return, and markets tend to respond to price signals. For example, no one is likely to build renewable generation if they cannot sell the output for a price that provides a return on their investment unless they have access to other revenue streams. Similarly, no-one is likely to build an electrolyser or a hydrogen storage facility without having access to cheap electricity to run it or a high sale price for the hydrogen produced. So, there could be step changes in supply, then demand, then supply and so on as market participants respond to market price signals in a lagged fashion. Each lag causes delays, so the deployment of flexibility could potentially be too slow to reach net zero by 2050 without incentivisation. Investment needs long-term price signals, long term contracts or support through a policy/market mechanism, such as the Contracts for Difference scheme that has driven increases in wind generation capacity and cost reductions.

Get involved in the conversation

We'd love to hear your thoughts on energy system flexibility and how these markets may develop in future. Get in touch with us at box.fes@nationalgridso.com.

[5] This is the downward influence on the wholesale electricity price by variable weather-driven generation such as solar, onshore and offshore wind at times of high output. Not having to purchase fuel means solar and wind have lower running costs than other generators and can undercut their competitors on marginal cost. The more the wind blows and the sun shines, while generation is enough to meet demand, the greater the decline in prices on wholesale markets. This can lead to low or even negative wholesale power prices, reducing the revenue for renewable generators. As new renewable generation will likely generate electricity at similar times to existing renewable generation this can impact the investment case for new renewable generators.