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Generating partners

Can nuclear and renewables learn to live together to keep Britain's lights on? **Tony Roulstone** examines the issue

MUCH IS MADE OF THE competition between nuclear and renewables. At first, it was about green credentials. Then it was about who got the R&D resources. Now the competition is about energy price and market share. This strategic competition has had benefits in reducing the cost of low-carbon energy and forcing nuclear to account for its previously hidden costs – e.g. waste, decommissioning and disaster insurance.

Some have seen this competition as fight to the death of one or the other technology. In fact, the pressures of climate change are pushing in a completely different direction, where nuclear and renewables will have to find ways of working together. The common enemy is fossil fuel. It is not about renewables or nuclear. Both will be required to replace fossil fuels and keep the lights on. How can these technologies with their different characteristics work together to ensure that we have clean, dependable and low-cost energy?

The scale of change in the energy system over the next 20 years will be huge. The UK is now in an apparently good position, see top right pie chart, with a mix of gas (39%), nuclear (24%) and renewables (20%). Carbon intensity is falling too – down from over 600g/kWh in 2000 to about 300g/kWh now.

The challenge now is to reduce demand, and to cut the carbon intensity to below 50g/kWh in the next 20 years. This is required both to meet carbon targets and to allow other energy demands, such as electric cars and heating, to be electrified.

The UK's residual coal and oil generators will be closed down by 2025. Current gas generation will still be required for its low cost and its flexibility, but gas generation will be limited to about 10% of the total to meet carbon targets. The whole of the rest of the electricity supply must be low-carbon – which probably means wind, solar and nuclear, plus some biomass as now (10%).

A possible scenario for 2030-2040 is shown in the bottom right pie chart. Wind costs for onshore and offshore turbines are falling. They are lower than solar costs, so wind is likely to take up much of the expansion, tripling installed capacity from 20GW to 60GW and also tripling production to 35% of the total, with a combined renewable share rising close to 60%.

Based on current government plans, existing nuclear is replaced with some growth in capacity and a production share of 33%.

Intermittency

One of the key issues of operating with this sort of energy mix is the apparent inflexibility of nuclear and the intermittency of renewables. This highly variable supply (see Figures 1&2 typical winter wind and summer solar supply), when superimposed on the daily, weekly and monthly variations in demand, makes the overall energy system unstable.

Nuclear and renewables have very different characteristics. Nuclear is dependable but inflexible. Renewables are intermittent and extremely variable.

Because of their nature there is little offsetting of variability between wind and solar. Wind makes a positive contribution during the winter when demand is high, but otherwise wind variation seems to be well correlated, unless the turbines are situated several hundred miles apart. So even when dispersed, wind generation does not provide steady power. Renewables also place costs on the systems that are not recognised by the headline 'cost of electricity' calculation used in energy planning. Backup, balancing, grid connections and grid reinforcement costs increase along with the share of renewables and are borne by the overall system. The OECD estimates these extra costs are around £20/MWh for onshore wind, £30/MWh for offshore wind and £45/MWh for solar.

The variability of supply and demand has two effects. In a market-based system, electricity prices will be very volatile. We are already seeing periods of negative electricity prices followed by high price spikes. Secondly,

Below: **Variability in the UK's low-carbon energy supply** (Source: Gridwatch Templar)

Figure 1: Nuclear & wind supply December 2017

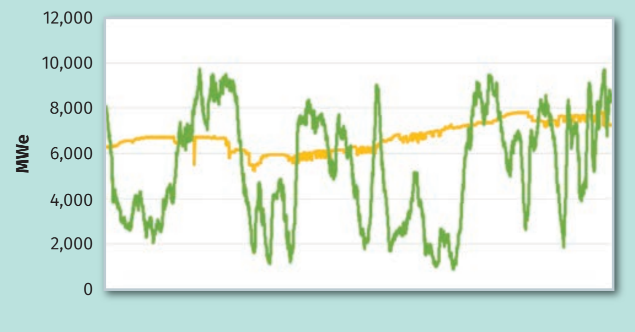
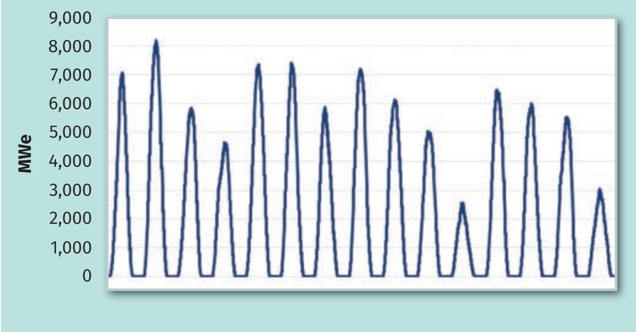


Figure 2: Solar PV output two weeks in July 2017



Left: **Offshore wind farm in the UK**

the variability means that either very large amounts of standby generation is required, or demand is not satisfied and some users are off supply.

What can be done to stabilise the system? As well as better demand management, there are two technical approaches: energy storage and nuclear flexibility (i.e. load following). All three will be required.

Storage is seen as the main hope. There are a range of storage options, including batteries, compressed air or hydrogen but there are questions about their efficiency, scale and cost. Lithium-ion batteries are efficient and their prices are falling. Larger and larger grid-scale batteries are being planned, but what is the scale of smoothing that is required?

Substantial amounts of capacity are required in all periods (hourly, daily and weekly), but the capacity increases with the length of period considered. Renewables reduce the requirement for management of supply or demand to some extent, within a day and over several months. Wind levels are higher in the winter, when demand is higher than in the summer. In all the other periods of time, renewable variability is the main reason why high volumes (many thousands of GWh) of load balancing is required.

Balancing supply & demand

Tesla has built a battery in Australia with a capacity of 130MWh and similar-sized batteries operate in California and are being built in South Korea. The economics of batteries make them suitable for short periods of standby – usually about an hour. Thirty Australian-scale batteries (at a UK cost of about £1 billion), would be required to backup the one-hour period variability. Though the cost of batteries is falling, they are not currently economic for storing energy across a single day without capital cost subsidies (see Lazards *Levelized cost of storage 3.0*). Longer periods are simply beyond the scope of battery storage, with potential costs in the many hundreds of billions. The size of battery required increases sharply for longer balancing periods, and the revenue – which is related to the number of times it is used each year – falls.

For periods beyond a few days, a different approach is required. Residual gas generation (~2500GWh) and more flexible nuclear could provide the solution for longer periods, together with a degree of system supply management. The system operator reduces the number of plants online in the summer and ensures that everything is available to meet peak winter demand.

What level of load-following would be possible with nuclear? Though the advanced gas cooled reactors, which provide most of the electricity in the UK, are not suitable for load-following, many nuclear plants can vary output.

The economics of nuclear are directed towards baseload operation, but nuclear plants in France and Germany regularly vary their power in response to demand changes. All new reactor designs allow for load-following at a rate of up to 5% per minute between about 50% and 100% power, several hundred times per year. More practical limits for power change for large reactors are probably ~1% per minute, but as a recent US study by Jenkins et. al in *Applied Energy 222 (p872-884)* shows, this small level of load-following is valuable in stabilising an electricity grid. It ameliorates fluctuations in electricity price and reduces system costs.

Small modular reactors are being proposed by NuScale, Rolls-Royce and others. These may also be better suited to supply management, either because of their ability to load-follow, or because their smaller capacities make matching demand simpler, by switching off the power plant when not required. Even if that is more expensive than baseload operation, its cost will be lower than renewables with long-term storage.

There are economic problems in delivering load-following. The high capital costs of nuclear make it most cost effective when operated continuously. A market-based electricity system such as in the UK does not give any premium for responding to demand, either by increasing or reducing supply.

Further, the pricing mechanisms being put in place for new nuclear (Contracts for Difference) will preclude such pricing signals. To make load-following for nuclear a reality, it will take a big change in the mind-set of operators, from 'always-on' to flexible generation. This must first be led by changes to the energy market to provide the incentives that will make load-following economically attractive.

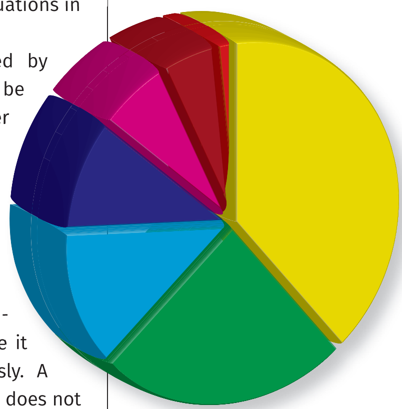
Living together

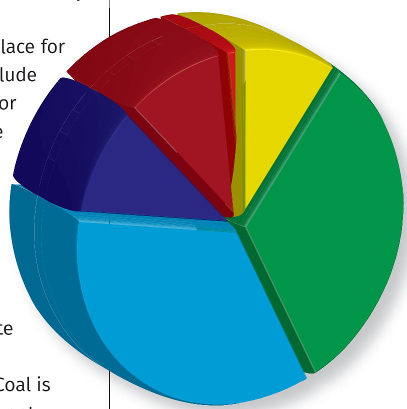
The future of energy systems is going to look quite different. Baseload is gone. Variable supply and variable demand will both have to be managed. Coal is destined to end and gas will be cut. The replacement power will be intermittent renewables – largely wind in Northern Europe and large volumes of solar PV in sunnier climes, where there is also lots of space. Gas's system balancing role will be much reduced. At the same time, variability will be much increased.

While both demand management and storage have roles to play, unless nuclear and renewables learn to live together, the future is bleak for addressing climate change. With better alignment of these two technologies making use of their different strengths, the challenges can be overcome. ■

Below: **UK electricity production – current share**

- Gas 39.1%
- Nuclear 24.5%
- Wind 12.8%
- Bio including co-firing 10.2%
- Coal, oil etc 6.6%
- Solar PV 5.2%
- Hydro 1.6%





Above: **UK electricity production – 2030/40 scenario**

- Gas 10%
- Nuclear 33%
- Wind 35.2%
- Bio including co-firing 10.2%
- Coal, oil etc 0%
- Solar PV 10%
- Hydro 1.6%