Net Zero - Technical Annex: Integrating variable renewables into the UK electricity system

Introduction and summary

Variable renewable electricity - such as large scale onshore wind, offshore wind and solar PV - is now the cheapest form of electricity generation in the UK and can be deployed at scale to meet UK electricity demand. In 2018 these sources provided 22% of the UK's electricity. That proportion rises to 50-65% in our scenarios to 2030, and potentially higher towards 2050.

Variable (or 'intermittent') renewables - which are weather dependent - are different to other forms of electricity generation, and increased deployment of them could require additional system services. For example, renewables cannot be guaranteed to generate during winter peak demand periods, and renewable output is generally correlated across different sites. Similarly, wind and solar generation can change substantially over periods of just a few hours, requiring non-renewable plants to be held in reserve to meet any sudden shortfall in supply.

All technologies, including non-renewable technologies, have system costs which need to be taken into account. For example, a large power station or interconnector may require network upgrades, or for the system operator to hold reserves in place for if the plant or connection fails. This Annex focuses on the system costs of variable renewables only.

This Annex supports the Committee's advice on setting a target to reach net-zero greenhouse gas (GHG) emissions in the UK by 2050.[1] In that advice we set out scenarios, based on a 'Further Ambition' scenario, to show how the UK can reduce GHG emissions to net-zero across the economy by 2050.

A net-zero economy requires near-zero emissions from almost every sector. If intermittency in the power sector requires gas-based back-up or reserve, this could increase emissions. Similarly, a lack of deployment of system flexibility could restrict the deployment of renewables and increase costs. Our Further Ambition scenario for the power sector sees low-carbon sources providing 100% of power generation in 2050, through a mixture of variable renewables (57%), firm low-carbon power like nuclear or plants fitted with carbon capture and storage (38%) and decarbonised gas such as hydrogen (5%).

The drivers of the system impacts of renewables are well understood, but uncertainty remains about the additional costs weather-dependent renewables will impose on the system at high annual and instantaneous penetrations.[2] This Annex aims to summarise the evidence on the costs of intermittency, and the challenges that may arise with deep penetrations of variable renewables on the UK's electricity system.[3] A detailed description of a net-zero power system, and the steps necessary to achieve this can be found in Chapter 2 of *Net Zero - Technical report*.

[1] CCC (2019) *Net-Zero: The UK's contribution to stopping global warming* and CCC (2019) *Net-Zero - Technical report*.

[2] Variable renewables will have different impacts over different timeframes. Section 2 considers the evidence around high annual penetrations of renewable generation. Section 3 summarises impacts of high instantaneous penetrations of renewables.

[3] The CCC would like to thank UKERC, Imperial College and National Grid for their input into this technical annex.

Key messages:

- Intermittency of renewables does not prevent full decarbonisation of the power system. Deployment of variable renewables, alongside system flexibility, is a low-regrets and low cost means of decarbonising the UK's electricity system.
- Intermittency does imply a real, but likely high, economic and technical limit to shares of individual renewable technologies within the UK's generation mix. The precise limit is unknown, but in total is likely to be higher than the 57% penetration assumed in our Further Ambition scenario. Additional system flexibility can increase the share that can be accommodated, with higher shares generally associated with lower overall system costs.
- Power sector decarbonisation does not rely on variable renewables alone, but a portfolio of technologies including nuclear power, bioenergy with CCS and decarbonised gas via CCS or hydrogen. Other renewables, such as wave and tidal, could also play a role.
- The costs of intermittency can be estimated, and ideally reflected in policy and market design. Overall, the costs of intermittency represent a small proportion of overall system costs. Policy should support system flexibility.

This Technical Annex is set out in four sections:

1) Drivers of intermittency

2) Evidence on costs and the value of flexibility

3) Future integration challenges

4) Policy implications

1) Drivers of intermittency and system flexibility

Drivers of intermittency

An effective electricity system provides electricity where it is needed, when it is needed. Historically, power systems have relied largely on increasing or decreasing production from flexible thermal power plant – such as gas, coal or biomass generation – to ensure supply matches demand at all times.

Nuclear power plants are typically run to maximise output at all times (known as 'baseload' or 'firm' power). Variable renewables like wind and solar vary generation in line with wind patterns and solar irradiance. As more variable renewables come onto the UK's electricity system, matching supply with demand at all times becomes harder (Box 1).

A decarbonised power sector that is not properly managed could put security of supply at risk and/or prevent the system from accommodating renewables, with associated costs. However, with good management, these costs and risks can be avoided.

In 2018, with 22 GW of wind and 13 GW of solar capacity, wind and solar provided 22% of generation and there were no periods in the year where low-carbon generation exceeded demand.[4]

However as deployment increases (consistent with reducing carbon intensity to under 100 gCO_2/kWh in 2030 and 10 gCO_2/kWh by 2050) there would be challenges in using the available generation fully, in meeting peak demand at certain times, and in meeting other system balancing requirements such as reserve and response:

- **Meeting peak demand.** In particular there may be periods where demand is high, but intermittent renewables make a limited contribution to meeting it. To ensure the system is secure and reliable there needs to be enough firm capacity to meet peak demand with low contribution from intermittent sources.
- **Using available generation.** With high penetrations of intermittent renewables there are likely to be periods where output is in excess of demand. This output would effectively be wasted and have no value.
- **Balancing requirements (e.g. reserve and response).** There would also be challenges to balance the system and maintain grid frequency. That could require additional system flexibility, such as battery storage, or 'part-loading' of decarbonised gas plant, to be able to respond to rapid changes on the system.
- **Networks.** Renewables - such as wind in Scotland, or in the North Sea - may be located far from where electricity is needed. Additional investments in electricity networks could be required to transport this electricity.

Improving system flexibility can help to meet these challenges. Even with high flexibility, challenges and costs will remain - our net-zero scenarios include all relevant costs to meet the four challenges above and ensure security of supply is maintained.

[4] CCC analysis of Drax (2018) *Electric Insights*.

Box 1. Variable renewables

Variable renewables such as wind and solar only produce power when the wind blows and the sun shines, whereas traditional power stations can generate electricity constantly over the year, and moderate their output flexibly in order to match electricity demand.

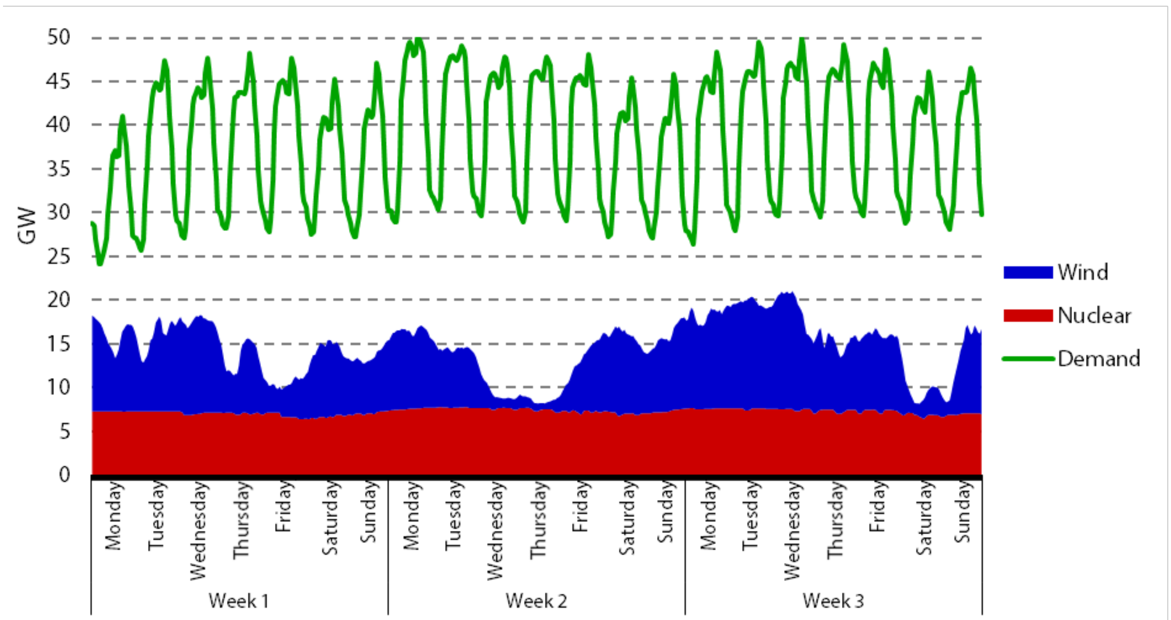
Weather patterns in the UK fluctuate over the year, from small changes in cloud cover and wind speeds within a period of just a few hours, to seasonal swings in solar output (higher in summer) and wind generation (higher in winter). In 2018, wind power provided 18% of total electricity generation (and solar PV another 4%), but generation within any single half hour of the year can vary significantly: on average the wind fleet produced around 40% of its potential power generation over the year, though this varied between close to 0% and near 100%. The CCC's scenarios for 2030 and 2050 include penetrations of wind and solar PV of up to 65%.

Figure B1.1 shows generation from wind and nuclear power output in the first three weeks of January 2018, compared to electricity demand. Whilst nuclear power was fairly constant over this period, wind output ranged from 90% of potential output to just 5%. Additionally, wind output changed by up to 12% from hour to hour, and 26% over a three hour period.

Other forms of capacity may be needed, to compensate for this variability. Paying for these 'reserve' plants to be available when the wind doesn't blow (capacity) and to be able to vary their output over short periods of time (reserve and response) makes up the majority of the 'system integration costs' discussed in this annex.

Similarly, solar will have lower output during winter periods (requiring capacity), though short-term variations in its output will be more predictable and its higher generation during the daytime generally will be advantageous.

Figure B1.1. Generation from wind and nuclear; electricity demand (first three weeks, Jan 2018)



Source: CCC Analysis based on Drax (2019) *Electric Insights*.

Options for system flexibility

Improving electricity system flexibility is key to keeping the costs of integrating variable renewables into energy systems low. In particular, improvements in flexibility can provide low-carbon sources of system reserve and response to minimise the need for part-loaded unabated gas plant, with associated emissions savings. Flexible systems also allow renewables and nuclear output to match demand better by shifting demand (demand-side response), supply (storage), or both (interconnection).

There are five main options for system flexibility:

- **Flexible gas plant.** There is currently 32 GW of unabated gas on the UK's system. More efficient and flexible generation technologies are available that can operate stably at lower levels of output, provide faster frequency response than at current levels, and consume less fuel when part-loaded to provide system reserve. Greater use of these would require less overall thermal plant to be built to stabilise the system, be less likely to curtail renewables output, and reduce overall emissions (until decarbonised gas is used).
- **Interconnection.** Interconnection already provides a valuable source of flexibility to the UK with 5 GW of capacity linked from GB to Ireland, France, the Netherlands and Belgium. Increased interconnection to these or other electricity markets (e.g. Norway) can improve security of supply and operating efficiency through sharing of backup capacity as well as ancillary services, and better accommodate intermittent generation by taking advantage of different weather patterns and/or electricity demand profiles.
- **Demand-side response.** Shifting electricity demand away from 'peak' time periods, such as on a winter evening and towards periods when demand is lower, is known as Demand-Side Response (DSR) or Demand-Side Management (DSM). DSR can help to manage large volumes of intermittent renewable generation and can significantly reduce the overall cost of a decarbonised system by shifting demand to off-peak periods with higher renewable output or by reducing the requirements for capacity during peak periods. DSR is also expected to be able to provide ancillary services such as frequency response.
- **Energy storage technologies.** There is currently around 3 GW of pumped hydro storage in the UK (equivalent to around 30 GWh). Further deployment of bulk and distributed energy storage (e.g. battery technologies) can reduce the need for additional backup capacity, generation and infrastructure, by storing electricity when demand is low and discharging when demand is high. Deployment of storage solutions is in the early stage, with around 0.4 GW of battery devices currently being used across the UK.[5]
- **Power-to-gas.** Converting power to hydrogen via electrolysis, could act as a form of energy storage, with the gas being stored (e.g. via salt caverns) and later being used for energy production. Electrolysers could also act as a flexible form of energy demand, and provide electricity system services.

Value of system flexibility

Improvements in system flexibility have the potential to bring electricity system costs down by £3-8 billion/year by 2030 (to a total system cost of around £30 billion/year) and £16 billion/year by 2050 (to around £50 billion/year), by making better use of low-carbon

[5] BEIS (2019) *Renewable Energy Planning Database*.