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Intermittent Electricity Generation

Sources of electricity that exhibit uncontrolled increases or decreases in output are often referred to as intermittent. This POSTnote examines the effect of wind, solar, wave and tidal intermittency on electricity prices, carbon dioxide emissions and the provision of electricity to meet demand. The note also describes measures to manage intermittency.

Overview

- Wind, solar, wave and tidal sources provide less flexible supply than fuel-burning generation. In addition, these renewable sources cannot be relied on to generate most of their maximum electricity output at all future times of high electricity need.
- These challenges can be managed using fuel-burning generation, imported electricity and electricity storage, and by shifting demand. Some of these will be supported by the Government's new Capacity Market.
- A combination of renewables with these options to manage intermittency may provide cost-competitive, reliable electricity.
- Wind's intermittency may increase the CO_2 emissions intensity of fossil-fuelled generation.

UK's Changing Electricity Generation

Wind and solar energy were used to generate 8% of UK electricity in 2013. The proportion of electricity from these sources, combined with electricity from new wave and tidal sources, is set to increase to 24% by 2020 to meet EU renewable energy targets.[1] Government is supporting this increase in renewable generation (Box 1). A further increase is likely in the longer term to help the UK meet proposed EU greenhouse gas emission and renewable energy targets for 2030 and the UK's target to reduce greenhouse gas emissions by 80% from 1990 levels by 2050.

Box 1. UK Government Support for Renewable Generation

The Government is supporting an increase in renewable generation through the following three schemes, which are funded by levies on consumer bills:

- Feed-In Tariffs (FITs) have supported small-scale low-carbon electricity generation, such as solar panels, since 2010. FITs guarantee generators fixed payment for their electricity.
- The Renewables Obligation (RO) is a requirement for electricity suppliers to source a specified proportion of their electricity from renewable sources. The RO supports large-scale renewables, such as wind farms, which must have RO accreditation before 2017. Support for accredited generators lasts for 20 years.
- Contracts for Difference (CfDs) will support large-scale renewables from 2014, initially running in parallel with RO. CfDs will guarantee renewable electricity generators a fixed price for their electricity for 15 years.

Existing and New Intermittency Challenges

All forms of electricity generation exhibit uncontrolled increases or decreases in output (intermittency). For example, conventional (fossil-fuelled and nuclear) power plants break down, causing larger instantaneous losses of capacity than renewables. However, the term intermittency is typically associated with the renewables: wind, solar, wave and tidal. Intermittency from these sources is characterised by very large variations in the amount of electricity they can provide at the national level. Although these variations are not normally controlled, they can be predicted with some accuracy (Box 2). New intermittency from renewables provides challenges relating to:

- maintaining electricity supply
- managing intermittency cost effectively
- carbon emissions from other sources.

Box 2. Predictability of Supply

Renewable electricity output is predicted using information such as weather forecasts. Forecasts of electricity output made shortly before supply help to match supply and demand. The accuracy of forecasts made four hours before supply depends upon the energy source.

- **Wind:** UK wind output deviates from these forecasts by 4% on average; in 2012/13 maximum deviations were 35%.
- **Solar:** There is little UK data on the accuracy of these forecasts. In Germany, output deviates from these forecasts by 5% on average.
- **Tidal:** The tide, and therefore tidal power, is highly predictable.

Challenges to Maintaining Supply

Ensuring security of supply is central to energy policy. POSTnote 399 covers issues that affect security of supply in extreme circumstances, such as fuel import disruption. During normal operation, the ability of the electricity system to supply electricity to all users, all the time, requires:

- reliability: sufficient generation infrastructure to be able to supply electricity to meet demand all the time reliably
- flexibility: the ability to quickly and controllably vary supply to match predicted and unpredicted fluctuations in demand. Without this match, supply failures would occur, risking blackouts.

Intermittent renewables affect how the electricity system maintains sufficient reliability and flexibility.

Contribution of Renewables to Reliability

Output of intermittent renewables varies according to a range of factors, principally changes in the weather. This variation affects their contribution to reliability and can mean other forms of supply, such as electricity storage, or temporary demand reduction, is needed to supplement renewables (see managing intermittency).

Measuring Contribution to Reliability

To assess and compare the contribution of individual intermittent technologies to reliability two types of measures are used. The first type measures 'reliable capacity', which is the amount of electricity expected to be available (with a low risk of it not being available) from a particular technology at all times of annual peak demand (52 Gigawatts (GW) in 2013). The second type compares the contribution of intermittent technologies by measuring reliable capacity as a proportion of a source's maximum capacity. For example, in 2013 UK wind power could produce 11 GW at maximum capacity, but only 7-25% of that figure was reliable capacity. Table 1 shows the proportions and the maximum capacity of the main renewable and conventional technologies. The contribution of solar (POSTnote 398) is zero because reliable capacity is measured at annual peak demand, which occurs in winter, after dark. Wind's contribution is not zero as the wind is generally blowing somewhere in GB.

Changes to Renewables Contribution

The contribution of intermittent renewables to reliability can increase or decrease depending upon a number of factors. A combination of different renewable technologies could contribute more to reliability than the sum of their individual reliable capacities. Further, if more renewable electricity was shared across Europe it would increase reliability, as local lows in output could be smoothed out by highs elsewhere. For wind, this would increase its contribution to reliability towards the average output of wind (27-38% of its maximum capacity). Conversely, an increasing proportion of a single technology may result in its contribution falling. For example, if the proportion of generation from wind rises towards 50%, the proportional reliability of wind will fall from 17-25% (in 2013) towards 7-9%.

Table 1. Contribution of Technologies to Electricity System Reliability at Times of Annual Peak Demand[2-6]

Technology	Reliable capacity as % of maximum capacity	2013 UK max capacity, GW
Wind	7-25%	11.0
Solar	0%	2.7
Hydro	79-92%	1.7
Tidal*	35%	<0.001
Wave*	35%	<0.001
Fossil-fuelled and Nuclear	77-95%	78

*There are little data available on the contribution of tidal and wave.

Contribution Towards GB Electricity Security

To secure GB electricity supply, the sum of all reliable capacity should be equal to peak demand, plus a small excess to mitigate against the risk that available electricity supply could fall below the estimated reliable capacity. This excess also minimises 'the amount of time National Grid is expected to have to use emergency measures', which the Department of Energy and Climate Change (DECC) has concluded is a more rigorous measure of system reliability. Box 3 outlines current assessments of future reliability.

Flexibility and Operating Constraints

Flexibility is necessary to allow electricity suppliers (wholesalers of electricity), generators and National Grid to keep the electricity system working (Box 4). As intermittent renewables replace fossil-fuelled generation, the system's flexibility will be affected in two ways:

- the amount of flexibility available will decrease
- the need for (some forms of) flexibility will increase.

Loss of Flexibility and System Inertia

Intermittent renewables offer limited flexibility. Their output is rarely used flexibly as it is usually economic for the market to use all their electricity (rather than electricity from other sources) because the running cost of intermittent renewables is very low. However, their electricity output can be reduced if required; but the reduction will be limited if renewable output is low. A service that intermittent renewables cannot provide is system inertia (Box 4). There will be an increasing need for options (see below) to maintain system inertia and flexibility as conventional generation is displaced. Without these options the use of renewables may be constrained (Box 5).

Box 3. Assessing Future Reliability

To monitor the amount of reliable capacity, assessments are done by the DECC, National Grid and Ofgem, the GB electricity market regulator.[2,3,4,7] Estimates made in 2013 show the excess of reliable capacity over winter peak demand falling until winter 2015/16. The fall is primarily due to a drop in total capacity, particularly coal power plant closures because of European legislation. Central estimates of the amount of spare capacity for the 2015/16 winter, range from 4% (Ofgem) to 7% (DECC). These differ because of assumptions about the reliability of imported electricity and the level of demand for electricity.[7] Ofgem's reference estimate is that National Grid would be required to use emergency measures for three hours per year, which is DECC's maximum acceptable level. National Grid's emergency measures can support a deficit of 2-3 GW.

Increased Flexibility Requirements
The amount of flexibility required by the electricity system is increased by intermittent renewables because of variations in their output that may or may not be predicted.

- **Unpredicted variations** in supply, such as a drop in wind power output, have to be compensated for by an equivalent change in output from flexible supply (or demand). The need for flexible balancing services (Box 4) which can compensate for an unpredicted variation within 2-240 minutes will increase by around 2 GW from 2014-25, due to intermittent renewables. The effect of different intermittent renewables depends upon the size of their unpredicted variations (Box 2).
- **Predicted variations** from intermittent renewables (over hourly timescales) are larger than those from conventional generation and will increase the financial value of flexible supply and demand options (see below).

Box 4. Matching Supply and Demand
To keep the electricity system working, suppliers and generators attempt to match predicted supply and demand through pre-arranged agreements. However, because of unpredicted changes, generators and suppliers do not always meet their exact contracted levels of supply or demand at each moment. When this occurs the **System Operator** (SO), National Grid in GB, intervenes in its role to balance supply and demand. The SO ensures moment-by-moment supply and demand match by making relatively small, but crucial, adjustments to supply and/or demand at each moment using back-up generation or agreed stoppages to some electricity users' supply. These interventions take different lengths of time to respond (see table), so they are used in different ways.

- When an imbalance between supply and demand first arises, an in-built property of the electricity system, **system inertia** allows power to be maintained, but only briefly. System inertia is provided by the rotating turbines in conventional generation, but only while they are in operation. If there are more rotating turbines in the generation mix, there is more system inertia and this allows the electricity system to remain stable for longer given an imbalance between supply and demand.
- After the initial imbalance the SO's flexible **balancing services** 'frequency response' and 'operating reserve' are used to maintain balance for different lengths of time (see table). The SO may have contracted these in advance or purchased them from a competitive market. In 2014, National Grid is set to reserve an average of 2 GW of frequency response and 5 GW of operating reserve.

Response Time of System Inertia and Balancing Services

Name of service	Response time	Time to maintain
System Inertia	0 seconds	~10 seconds
Frequency Response	2-30 seconds	Up to 30 minutes
Operating Reserve	2-240 minutes	15-120 minutes

Box 5. Constraints on Level of Intermittent Renewables
The proportion of electricity that the network can accept from intermittent renewables may be limited by a variety of factors at any point in time. Constraints include:

- the need for some system inertia at all times
- the need for a certain amount of balancing services (Box 5) – for example, in Ireland it is estimated that in the period up to 2020 a combination of need for system inertia and balancing services will limit the proportion of electricity generated from intermittent renewables (plus imported electricity) at any moment to 75%
- limited capacity for electricity flow on the local or national electricity transmission network
- insufficient electricity demand at times of high supply.

If one of these issues leads to electricity from intermittent renewables being constrained when it was contracted to be used by a supplier, the generator is still paid by National Grid. In GB, wind power has been constrained because of low local network capacity caused by network outages. National Grid has estimated that it will constrain some wind power on about 38 days per year by 2020 because of flexible service requirements.[8]

Managing Intermittency

There a number of options for managing the reliability and flexibility challenges of intermittency highlighted above. Calculating the cost of managing intermittency allows the relative merits of intermittent renewables to be compared against competing generation technologies.

Managing Predicted Variations and Low Reliability

The challenges of greater predicted variations, lower reliability and reduced flexibility that intermittent renewables present can all be managed using existing or new flexible supply and demand options. Without these, intermittent renewables can only provide sufficient reliability if very large amounts are built, but as a result a lot of their generating capacity would go unused. Nuclear power (POSTnote 457) is not usually considered as a flexible supply option; it currently offers little flexibility to supplement renewables, although future designs could offer more. The four remaining flexibility options are outlined below.[9,10]

Flexible Fuel-Burning Generation
Gas, coal and biomass-fuelled power plants can provide additional reliable capacity. Most flexibility in the current electricity network is provided using these. To match the low-carbon credentials of renewable generation, gas or coal-fuelled generation may be combined with carbon capture and storage (POSTnote 335).

Connecting to Overseas Electricity Networks
Imported electricity can provide additional reliable capacity. The GB network is currently connected to the Irish Single Electricity Market and North-West Europe, with a total capacity of around 4 GW. There is little experience to test the reliability of electricity from imported electricity if both interconnected countries are tight on supply. DECC currently assumes that potential imports from Europe provide reliable capacity, while Ofgem does not in its reference scenarios of future GB security of supply.[7]

Electricity Storage
Electricity storage allows power generated when intermittent supply is high (or demand is low) to be stored for release when supply is low (or demand is high). The combination of intermittent generation and storage delivers more reliable capacity. POSTnote 306 on electricity storage covers the different technologies. Pumped hydroelectric storage provides the largest capacity in GB (2.7 GW in 2013[5]), but its expansion is limited by suitable geographies.

Changing Patterns of Demand
Rather than providing back-up supply for times of low intermittent supply, it is possible to temporarily reduce demand using incentives (POSTnote 452). This reduces the reliable capacity required by the electricity system. National Grid has agreements with electricity users that allow it to reduce 1.6 GW of demand. It is also possible to incentivise electricity users to increase demand at times of high supply.

Managing Unpredicted Variations
To manage unpredicted variations there must be sufficient system inertia and balancing services (Box 4). System inertia could be provided by some forms of electricity storage in addition to conventional generation. Alternatively, industry is developing a substitute, which allows very fast flexibility that responds in under two seconds. The growing need for balancing services could be offset by improved weather predictions. Otherwise, balancing services can be provided by the four options presented above for managing predicted variations.

Cost of Managing Intermittency
The options above may help electricity systems with a high proportion of renewables provide reliability and flexibility in a cost efficient and potentially cost competitive manner. To compare the overall cost of intermittent renewable generation against other forms of generation, the cost of managing intermittency may be added to the average direct cost of intermittent renewable electricity. (Many organisations also suggest adding the indirect cost of greenhouse gas emissions in comparisons.)

Estimates of the cost of managing intermittency typically include the cost of supplementary contributions to reliability and flexibility and expanded electricity grid capacity (to manage larger maximum flows of electricity). Estimates differ, but many commentators suggest that the incremental cost will rise as the proportion of intermittent renewables rise.[11] The Committee on Climate Change estimates that intermittency will add 1 pence per kilowatt-hour (p/kWh) to the cost of renewables when their share of total electricity rises to 24% in 2020.[1] For comparison, the direct cost of generating a unit of electricity from onshore wind is currently around 7.5-11.5 p/kWh and the average household uses 3,300 kWh each year. The Nuclear Energy Agency (NEA) estimates that the cost of managing intermittency if wind generates 10% or 30% of UK electricity to be 0.9 p/kWh or 1.6 p/kWh respectively, or between 8-21% of the direct cost of onshore wind.[12] For solar, the NEA estimated costs of 2.6 p/kWh or 3.5p/kWh.

Current Policy Responses to Intermittency
Accounting for the Cost of Intermittency
The current electricity market accounts for the cost of intermittency by rewarding reliability and flexibility. The 2013 Energy Act introduced a 'Capacity Market' that will pay generators in return for a commitment to deliver energy when needed. National Grid pays for its balancing services through a competitive market.

Support for Flexible Technologies
Fuel-burning generation, temporary demand reductions and electricity storage will all be eligible to compete for support from the Capacity Market. Electricity from overseas is not eligible under current proposals and the market will not differentiate based on flexibility.[13] Other support includes:
- DECC's £20m funding for innovation in energy storage
- Ofgem's 'Cash-out Reform', to ensure that flexibility is correctly priced by the electricity market
- National Grid's proposal to require very fast flexibility from generators not contributing system inertia
- National Grid's new Demand-side Reserve, which will pay users to reduce demand during annual peak demand.

Effect on Carbon Emissions
The Government's Carbon Price Floor taxes Carbon Dioxide (CO_2) emissions on the basis of direct emissions. CO_2 emissions from renewable electricity generation are significantly lower than from fossil-fuelled generation (see POSTnote 383). However, the intermittency of renewables has two effects that may reduce their CO_2 savings.

Changing the Operation of Fossil-Fuelled Generation
The use of intermittent renewables is likely to make the operation of fossil-fuelled generation more variable. This will usually increase the emissions (per unit of electricity) from fossil-fuelled generation, offsetting some potential CO_2 savings. Estimates of the level of offset vary significantly depending upon the detail of analysis and country considered. In general, the proportion of CO_2 savings offset becomes greater as the amount of intermittent generation increases. Early results from detailed modelling commissioned by DECC suggest that around 6% of potential GB CO_2 savings could be offset if about quarter of GB electricity is provided by wind in 2020.

Encouraging Different Flexible Technologies
Increased levels of intermittent renewables may encourage some of the flexible technologies listed above. These may produce additional emissions or if displacing another technology, differing emissions. It has been suggested that the variable operation of fossil-fuelled plants will redirect investment in new fossil-fuelled plants towards higher carbon intensity plants rather than cleaner plants. Modelling indicates that more higher carbon intensity plants may be built. However, it also suggests these would only be operated for a short time in total, resulting in just a small cut to potential CO_2 savings.

Endnotes
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