March 2017

Briefing

Keeping the UK's lights on

The three main goals for the UK's electricity system are that is clean, affordable and reliable.

This briefing focuses on reliability, and how a renewables-centred electricity grid can keep the lights on.

Renewables in the UK are growing at an astonishing rate - up from 7% to 25% of UK electricity in just 6 years[1]. This is cleaning up our electricity system, and creating new jobs and industries. And the lights have stayed on.

Around the world, from China to Kenya, Brazil to Germany, the story is the same: plummeting renewable energy costs[2,3], rocketing deployment. This, allied to spectacular technological developments in energy storage, means we can now envisage an almost fully renewable future for electricity, one that could happen far faster than politicians believe. And the lights can stay on in future, as they do now. This briefing sets out:

1. How the electricity system will need to change in future
2. The biggest risks to the lights going out - ageing coal and nuclear plants and extreme weather, not renewables
3. The safeguards that currently keep the lights on
4. How the safeguards that keep the lights on will need to change in future
5. How to keep the lights on when the wind doesn't blow and the sun doesn't shine
6. Costs
7. Policy changes needed

1. How the electricity system will need to change in future

For the UK to do its part in tackling climate change one of the most urgent tasks is to decarbonize our electricity supply. According to the Committee on Climate Change the UK needs to have decarbonized electricity to 50gCO_2/kWh by 2030[4], from around 330 gCO_2/kWh in 2015[5]. To achieve this Friends of the Earth argues that around 75% of our electricity should come from renewables by 2030,[6] moving to a zero carbon system shortly after. Coal power should be gone by 2023; by 2025 at the latest according to the Government's recent consultation. Gas will need to reduce in prominence in the 2020s in order to decarbonize the grid by 2030. Large-scale biomass and nuclear have significant environmental issues should be minimized and phased out.

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/547977/Chapter_6_web.pdf
[2] https://www.bloomberg.com/news/articles/2016-12-15/world-energy-hits-a-turning-point-solar-that-s-cheaper-than-wind
[3] http://www.climatechangenews.com/2016/10/21/renewables-undercut-new-coal-plants-in-south-africa/
[4] https://www.theccc.org.uk/wp-content/uploads/2013/12/1785b-CCC_TechRep_Singles_Chap2_1.pdf
[5] https://www.gov.uk/government/statistics/digest-of-united-kingdom-energy-statistics-dukes-2016-main-chapters-and-annexes
[6] https://www.foe.co.uk/sites/default/files/downloads/renewable-century-new-briefing-102436.pdf

This transition is not only achievable, it is underway. And it will be good for us – improving people's health and environment and boosting the economy. But it is an urgent challenge, requiring immediate, stepped-up action.

> 'The idea of large power stations for baseload is outdated'
>
> - Stephen Holliday, former Head of National Grid in 2015.[1]

Our future electricity system will likely be a combination of high levels of renewables (largely of offshore wind, solar, onshore wind and marine energy sources – FOE's estimates suggest 65% of power from intermittent sources by 2030, and a further 10% from less variable sources like tidal , hydro and geothermal),[7] with lots of energy storage (batteries, dams, hydrogen etc), interconnectors, demand-side response and smart grids to manage demand and supply, and decreasing amounts of natural gas as back-up.

While many renewables are already recognized as cost-effective, it is now increasingly being accepted that in combination with storage and demand-response they can also provide reliable power, and form the central basis of a clean energy system.

2. The biggest risks to the lights going out - ageing coal and nuclear plants and extreme weather, not renewables

The UK has gone from 7% renewable electricity to 25% in just six years, without causing black-outs. The few problems which have occurred in this time are down to either extreme weather events, or failures in our ageing fleet of coal and nuclear power stations. The "variability" in electricity supply from wind and solar is dwarfed by the morning and evening surges and falls in electricity demand, which the grid copes with on a daily basis.

Blackouts are rare in the UK, and are not caused by the predictable and easily managed fluctuations in renewable generation. Most large-scale blackouts are caused when something catastrophic goes wrong as a result of an accident or extreme weather. By far the most common cause of blackouts is a fault with the grid distribution system – for example the December 2015 large scale blackouts in Lancashire[8] were caused by flooding affecting the substations and power lines – a situation which could itself become more common thanks to climate change, but which has nothing to do with the source of the electricity.

Occasionally blackouts may be caused by a problem with a generator – for example a fire at a power station.[9] In the UK there has been only one blackout in the last ten years due to problems with generation (caused by simultaneous outages at Longannet coal power station and Sizewell B nuclear power station)[10], despite the fact that fossil fuel and conventional power stations are forced offline quite regularly. Indeed, in the first nine months of 2015 there were 900 reported failures at coal and gas power stations in the UK, none leading to a blackout. [11] These outages may be large too. A nuclear power station may lose hundreds of megawatts of capacity in a few seconds, as happened

[7] https://www.foe.co.uk/sites/default/files/downloads/plan_cbe_report.pdf
[8] https://eandt.theiet.org/content/articles/2016/05/lancashire-blackout-apocalypse-a-massive-lesson-says-report/
[9] https://www.theguardian.com/business/2014/oct/20/didcot-b-power-station-blaze-oxfordshire
[10] http://eciu.net/assets/The-Lights-Seem-to-be-Staying-On-Realities-behind-%E2%80%98Blackout-Britain%E2%80%99-October-2015.pdf
[11] http://eciu.net/assets/The-Lights-Seem-to-be-Staying-On-Realities-behind-%E2%80%98Blackout-Britain%E2%80%99-October-2015.pdf

in 2015 when Hunterston B nuclear power station was closed by high levels of seaweed preventing it from taking in cooling water.[12]

3. The safeguards that currently keep the lights on

The reason why these sudden failures rarely lead to power outages is because the grid is good at dealing with sudden changes in demand and generation. To cope with sudden or unexpected changes the National Grid runs the Short Term Operating Reserve (STOR) and has a number of tools at its disposal, such as engaging different generators, using back-up electricity sources, paying companies to use power at different times (Demand Side Response), or temporarily lowering the grid's voltage. By comparison to the sudden loss of a large fossil or nuclear power station, or the daily spikes and troughs in demand, the gradual and predictable ups and downs of renewables are easy to manage and very unlikely to cause blackouts.

The Government has also brought in the "capacity mechanism" policy, to ensure enough "back-up" power is available over the winter, when demand is highest. This policy provides contracts to generators to ensure that there will be sufficient capacity available to power the country in the event that other forms of generation will not be available. In the most recent capacity market auctions 500 MW of new-build large scale battery storage was awarded contracts for the first time – showing the rapidly changing nature of the sector, while the equivalent of 800 MW of Demand Side Response has also been contracted.

3.1 How renewables fit in the current electricity mix

Far from causing the lights to go out when the wind doesn't blow, energy systems with lots of variable renewables can be very reliable. Germany and Denmark have the two most reliable energy systems in Europe, with four times fewer minutes of power outages than the UK, and some of the highest amounts of renewables[13]. Portugal too has successfully run its energy system on very high levels of renewables for many years. Partly this is due to overall improvements in grid management, but it is also partly due to the nature of renewables. A grid based on renewables is likely to be more diversified than one based on smaller number of centralized power stations. This means that if something does go wrong with one part of the system, it is far less of a threat to system security.

Some renewables – like hydropower and tidal energy – can be extremely regular. Others such as wind and solar are variable, meaning that they produce different amounts of power depending on conditions. Over the course of the year, this output is averaged out and called the load or capacity factor (the average amount of power that the plant produces compared to if it was running at fully production, 24 hours a day, 365 days a year). Table 1 shows the average load factors for a number of UK power generation technologies. Note that no power source has a 100% capacity factor as stations may come on and offline for balancing, maintenance or economic reasons, or there may be cheaper sources of electricity available – with the average for UK coal coming in around 39%.

While wind and solar may be variable, they are also increasingly predictable. Advances in information technology and weather forecasting have greatly increased the ability of grid operators to accurately calculate power generation from renewables from a day to five minutes ahead.[14] This means that other sources of generation can be available for those times when sufficient renewables are not available, or to cope with sudden spikes in demand for power - such as during the

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[12] http://www.bbc.co.uk/news/uk-scotland-glasgow-west-32970794
[13] https://www.cleanenergywire.org/dossiers/energy-transition-and-germanys-power-grid
[14] http://www.utilitydive.com/news/how-advanced-forecasting-is-making-it-easier-to-integrate-solar-onto-the-gr/270611/

Table 1. Load factors by technology in UK

Technology	Load factor (existing plant 2015)
Onshore wind	34%
Offshore wind	41%
Solar photovoltaic	12%
Hydropower (large)	41%[15] (same source for all renewable tech)
Gas CCGT	32%
Nuclear	75%
Coal	39.1%[16] (same source for all non-renewable tech)

commercial break in a popular TV programme, when millions of kettles are switched on. (To date the largest such event involved a spike of 2.8 GW during the 1990 world cup).[17] This is known as grid balancing, and is something the grid operators have always had to do to cope with.

4. How the safeguards that keep the lights on will need to change in future

Currently the UK relies largely on natural gas for flexible grid-balancing with some pumped water storage, and electricity imports from France.

In the future this will likely evolve in favour of larger amounts of energy storage (such as batteries, electric vehicles, more pumped water storage, compressed air storage or hydrogen). These can store energy from renewables when they are producing more than is needed, and release it when required. Other sources of flexibility and security will increasingly come from smart grids, greater interconnection with countries and Demand Side Response (DSR – see below). This pays energy consumers to shift their energy use to times when electricity is cheaper and more available – providing a benefit to the consumer and the grid.

4.1 Smart-grids are coming

It is not just improvements in energy storage technology that are making a renewable-dominated system realistic. Changes to the way the grid is operated, along with advances in information technology are leading to the emergence of a 'smart grid'. Rather than simply feeding power from generators to devices, a smart grid is a more complex two-way interaction. Energy users can communicate with the grid to store and release power at the most appropriate times, while others can shift their time of usage to take advantage of the cheapest or cleanest sources of power. For example, Norish - a cold storage business - can be flexible in the timing of its energy use for cooling, and has contracts to shift this demand to times when it will put the least stress on the grid.[18] This is known as 'demand side response' and can help eliminate sudden peaks in demand and make best use of renewables (for example by charging electric cars overnight when demand is low but it may be windy, or powering-up equipment during sunny afternoons when solar is abundant etc).

[15] https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes
[16] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/552059/Chapter_5_web.pdf
[17] http://www.walesonline.co.uk/news/wales-news/national-grid-braced-huge-power-11570977
[18] https://www.flexitricity.com/en-gb/case-studies/norish/

4.2 Electricity storage and smart grids will reduce the need for fossil fuel back up

There are many different forms of electricity storage. Some – such as flywheels, super capacitors, batteries, electric vehicles, compressed air and smaller pumped storage facilities – are likely to cover medium to short term needs. They would generally provide power for up to a few hours to cover short term changes in weather, short peaks in demand (famously the commercial breaks in popular television shows used to rely on storage as everyone put their kettles on), or unexpected faults. These systems can respond very quickly, preventing the lights going out and allowing other generators (such as gas turbines) to be turned on to take up the slack if needed.

Other forms of energy storage – like hydrogen gas or synthetically produced natural gas – can in theory be used to cover much longer gaps in generation. Hydrogen for example can be produced in a number of ways, including using renewable electricity or carbon capture and storage. This gas can then be stored until it is needed, and used to generate heat or electricity. In the future for example abundant solar power in summer might be stored as hydrogen for use as heating in the winter.

5. How to keep the lights on when the wind doesn't blow and the sun doesn't shine

The system copes fine with 25% renewables. But what might happen if we have 75%+ renewables, if there is no wind or sun for days at a time, for example on a series of cold, high-pressure days in winter? Could the UK balance its grid in future with a largely renewable system?

Studies by Poyry for the Committee on Climate Change have shown it can be done even with very high levels of renewables (up to 94%), using for example demand side management and small amounts (relative to overall generation) of natural gas.[19]

In these studied scenarios real weather data were taken from several of the past years and used to simulate what might happen in an electricity system powered largely by wind. Artificial years were also generated to stress-test the scenarios. These contained a large number of 'lulls' where winds dropped away, including prolonged 5-day lulls in winter. In these scenarios systems where up to 80% of the electricity system is renewable the grid could be managed with less than 10GW of additional flexible peaking capacity by 2050 (this may be gas with or without CCS, pumped storage or perhaps hydrogen generated during times of high renewable output). Higher renewable penetrations (i.e. up to 94%) were possible with more. Other models show similar mixes of very high levels of renewables with residual amounts of fossil fuels (less than 20%) to keep down the cost of balancing.[20]

The point is that while back-up *capacity* may need to be available, the more renewables there are, and the more diverse they are, then the less the back-up is actually used, gradually reducing the number of hours fossil fuels are burnt. Similarly interconnectors and demand side response reduce the number of hours for which back-up may be needed.

6. Costs

It should be possible and cost-effective to move to a system that is almost entirely renewable through a mixture of high levels of renewables, demand side management, energy storage and interconnectors with other countries to take advantage of shifting weather patterns.

[19] theccc.org.uk/archive/aws/Renewables%20Review/232_Report_Analysing%20the%20technical%20constraints%20on%20renewable%20generation_v8_0.pdf

[20] http://energydesk.greenpeace.org/2015/09/21/4-ways-the-uk-can-get-almost-all-its-power-from-renewables/

6.1 The cost of battery storage is falling quickly

The cost of batteries and other energy storage systems has fallen by around 14% per year since 2007[21]. As this continues it will make it cheaper to integrate large amounts of variable renewables onto the grid, reducing the need for fossil fuel back-up.

The shift to electric vehicles too will provide opportunities for greater use of energy storage to support the grid. Electric vehicles (new registrations of which were up nearly 30% in the first half of 2016 compared to the same period in 2015 in the UK)[22] can both charge from the grid, and release energy to it when they are plugged in. In the future large numbers of electric vehicles could be aggregated to provide power to the grid during times of peak demand, and charge during times of lowest cost electricity (likely times when renewables are abundant). Vehicle-to-grid trials are currently being conducted in the UK by Nissan and ENEL, which predict that 18,000 EVs could provide daily storage equivalent to 180 MW. Nissan say that if every vehicle in the UK was an EV *"vehicle-to-grid technology could generate a virtual power plant of up to 370 GW"*[23].

6.2 Renewables' costs are also falling fast

The cost of renewable energy is falling quickly. In many parts of the world, from California to Chile and South Africa[24], wind and solar are now the cheapest sources of new electricity. In the UK, even the government's conservative estimates show that onshore wind is now effectively the cheapest form of new generation available, in terms of Levelised Cost of Electricity.[25] Large scale solar in the UK will likely be competitive with new gas generation by around 2020, and cheaper before 2025. Similarly, smaller rooftop solar and offshore wind are seeing costs fall quickly (solar down 50% in five years). By 2025 it is estimated that offshore wind will be cheaper than new nuclear generation and competitive with gas generation soon afterwards (see Table 1), and this could happen much sooner as costs continue to fall more quickly than predicted. Indeed, many expect new offshore wind to be cheaper than new nuclear in the next round of auctions for government contracts (April 2017).[26]

Table 2. Government's projected LCOE costs of power (£/MWh). Source: BEIS 2016[27] (note: renewable costs subject to rapid change).

Year of Commissioning	**2018**	**2020**	**2025**	**2030**	**Notes**
CCGT Gas	61	66	82	99	
Onshore Wind >5MW	65	63	61	60	
Offshore Wind	114	106	100	96	Likely underestimate of cost reductions. LCOE £97/MWh reached in 2017.[28]
Nuclear			95	78	(35-year contract, all others techs are 15 year)
Large Scale Solar	71	67	63	60	Likely underestimate of cost reductions
Rooftop Solar Large	77	73	69	65	

[21] https://www.sei-international.org/mediamanager/documents/Publications/SEI-Nature-pre-pub-2015-falling-costs-battery-packs-BEVs.pdf.
[22] https://www.motoringresearch.com/advice/electric-hybrid/electric-car-sales-still-growing-fast-uk
[23] http://nissaninsider.co.uk/nissan-and-enel-launch-vehicle-to-grid-trial/
[24] http://www.climatechangenews.com/2016/10/21/renewables-undercut-new-coal-plants-in-south-africa/
[25] https://about.bnef.com/press-releases/wind-solar-boost-cost-competitiveness-versus-fossil-fuels/
[26] https://www.theguardian.com/business/2017/feb/12/uk-offshore-wind-will-lower-energy-bills-more-than-nuclear
[27] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/566567/BEIS_Electricity_Generation_Cost_Report.pdf
[28] https://ore.catapult.org.uk/our-knowledge-areas/knowledge-standards/knowledge-standards-projects/cost-reduction-monitoring-framework/

6.3 With balancing and storage renewables will deliver an affordable system

While the need to balance or build energy storage may add to the cost of energy, increasingly the combined costs of renewables and storage systems are still less than the alternative. New research show large amounts of storage and solar (up to 40 GW of solar), for example, will reduce the overall cost of power compared to business as usual.[29] The Committee on Climate Change estimated that the overall cost of balancing the grid (which to some extent is needed by all technologies, not simply renewables) at up to £10/MWh meaning that renewables will still be competitive.[30] Research by the UKERC supports this, indicating that costs of balancing intermittent renewables up to about 30% of the total generation (roughly twice as much as in 2016) will be around £10/MWh. [31] Beyond this cost estimates vary, depending on the level of flexibility in the grid. In a flexible grid system of the kind now envisaged whole system integration costs would likely remain modest, with a range of studies suggesting around £10-£17/MWh with 50% intermittent renewables. [32,33] Note that these 'costs' would not be uniform across technology – with some like offshore wind likely having lower integration costs (some models suggesting around £5.50/MWh in a moderately flexible system).[34]

7. Policies needed

Renewables, DSR and energy storage are all rapid growth areas for the UK economy. But these successes need a stable, clear and strong policy environment to ensure they continue. While Friends of the Earth has set out actions to boost renewable energy elsewhere,[35] areas relating to security and integration where Government should act are:

- **Strategy and targets**. The Government should announce a strategy and targets for energy storage and DSR in the March 2017 Emissions Reduction Plan, and ensure this is integrated with the Industrial Strategy. This should have as its aim the maximisation of renewable energy and seek to make the UK a world leader in demand response and energy storage, as recommended by the National Infrastructure Commission.[36]

- **Reform the energy market**. Tithe energy market needs to be reformed to promote and benefit from flexibility, low carbon technology and storage. This should allow the benefits of a flexible energy system and related services to be realised. Outdated regulatory barriers should be removed to allow storage and demand side response to compete fairly with other sources of generation.

- **Reform the capacity market**. Ensure that low carbon solutions like DSR and energy storage are prioritised in future iterations of the capacity market.

- **Financial incentives.** Any changes to the charging regime by OFGEM should incentivise network owners to use storage (and other flexibility mechanisms) to improve the capacity and resilience. Dynamic pricing and half hourly metering should also be introduced.

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[29] http://www.solar-trade.org.uk/wp-content/uploads/2016/10/Intermittency20Report_Lo-res_031016.pdf
[30] https://documents.theccc.org.uk/wp-content/uploads/2015/10/Power-sector-scenarios-for-the-fifth-carbon-budget.pdf
[31] https://www.carbonbrief.org/in-depth-whole-system-costs-renewables
[32] https://www.carbonbrief.org/in-depth-whole-system-costs-renewables
[33] https://www.e3g.org/docs/Whole-system_cost_of_variable_renewables_in_future_GB_electricity_system.pdf
[34] https://www.e3g.org/docs/Whole-system_cost_of_variable_renewables_in_future_GB_electricity_system.pdf
[35] https://www.foe.co.uk/sites/default/files/downloads/renewable-century-part-1-only-102438.pdf
[36] National Infrastructure Commission Smart Power Report
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/505218/IC_Energy_Report_web.pdf

- **Clear Operating and performance standards for energy storage solutions**. These should be defined by OFGEM, in consultation with a broad range of stakeholders

Conclusion

Renewable energy sources, combined with high levels of storage, demand side response and the ability to trade power across regions will be the best solution to decarbonize the UK's electricity system, delivering affordable and reliable energy. As such the UK government should recognize the benefits that such as transition will bring and plan and act accordingly. Key steps will include providing scale and certainty to the renewable electricity generation sector, by providing a route to market for solar and wind, and scaled-up delivery of offshore wind. Communities too should be engaged and encouraged to participate in the energy market, while the UK should implement the recommendations of the National Infrastructure Commission and aim to become a world leader in energy storage and Demand-Side Response.