August 2015 Energy Research Partnership

Managing Flexibility Whilst Decarbonising the GB Electricity System

Executive Summary and Recommendations

The Energy Research Partnership

The Energy Research Partnership is a high-level forum bringing together key stakeholders and funders of energy research, development, demonstration and deployment in Government, industry and academia, plus other interested bodies, to identify and work together towards shared goals.

The Partnership has been designed to give strategic direction to UK energy innovation, seeking to influence the development of new technologies and enabling timely, focussed investments to be made. It does this by (i) influencing members in their respective individual roles and capacities and (ii) communicating views more widely to other stakeholders and decision makers as appropriate. ERP's remit covers the whole energy system, including supply (nuclear, fossil fuels, renewables), infrastructure, and the demand side (built environment, energy efficiency, transport).

The ERP is co-chaired by Professor John Loughhead, Chief Scientific Advisor at the Department of Energy and Climate Change and Dr Keith MacLean (formerly Director of Policy & Research at Scottish and Southern Energy). A small in-house team provides independent and rigorous analysis to underpin the ERP's work. The ERP is supported through members' contributions.

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The Energy Research Partnership Reports

ERP Reports provide an overarching insight into the development challenges for key low-carbon technologies. Using the expertise of the ERP membership and wider stakeholder engagement, each report identifies the challenges for a particular cross-cutting issue, the state-of-the-art in addressing these challenges and the organisational landscape (including funding and RD&D) active in the area. The work seeks to identify critical gaps in activities that will prevent key low-carbon technologies from reaching their full potential and makes recommendations for investors and Government to address these gaps.

The views in this report are not the official point of view of any organisation or individual and do not constitute government policy.

This project was guided by a steering group made up of experts from ERP members and other key organisations, as listed below.

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We would like to thank all those who helped inform this work.

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Executive Summary

The Energy Research Partnership has undertaken some modelling and analysis of the GB electricity system in the light of the carbon targets set by the Committee on Climate Change. Firstly a brief examination was made of the German and Irish markets with the hope of learning from their advanced penetration of variable renewables. Secondly a new model, BERIC, was written to simultaneously balance the need for energy, reserve, inertia and firm capacity on the system and its findings compared with simpler stacking against the load duration curve.

The intention was to assess the need for flexibility on the system but some broader conclusions also emerged:

The Need for Zero Carbon Firm Capacity

A zero- or very low- carbon system with weather dependent renewables needs companion low carbon technologies to provide firm capacity

The modelling indicates that the 2030 decarbonisation targets of 50 or even 100 g/kWh cannot be hit by relying solely on weather dependent technologies like wind and PV alone. Simple merit order calculations have backed this up and demonstrated why this is the case, even with very significant storage, demand side measures or interconnection in support. There is a need to have a significant amount of zero carbon firm capacity on the system too - to supply dark, windless periods without too much reliance on unabated fossil. This firm capacity could be supplied by a number of technologies such as nuclear, biomass or fossil CCS.

The Need for Market Pull for Ancillary Services

Policy makers and system operators need to value services that ensure grid stability so new providers feel a market pull

Currently some necessary services (e.g. inertia/ frequency response) are provided free or as a mandatory service. However, traditional providers of these services (fossil plant) are closing or becoming uneconomic to run, and at the same time, demand is growing (especially for fast reserve and response). Weather dependent renewables are not consistent suppliers of these services but new providers can't develop in the absence of a market signal.

The Need for a Holistic Approach to Valuing Technologies

A holistic approach to system cost would better recognise the importance of firm low carbon technologies and the cost of balancing the system

The modelling has demonstrated that the value to the system of a technology is dependent on the existing generation mix and the services which that technology can provide. The former means that a technology cannot be characterised by a single number such as levelised cost of energy (LCOE). Firstly because energy is only one of a number of essential services that technologies provide to (or require from) the grid; and secondly because the existing grid mix has a very substantial influence on the value of the services provided by additional technology.

Whilst this report has focused on generation technologies, it is important to recognise that demand reduction through energy efficiency will have a role to play in reducing carbon emissions and must be considered alongside low carbon generation technologies.

Recommendations

- A much deeper examination of the issues raised within this report is needed. ERP's modelling and analysis has only begun to scratch the surface and ERP does not have the resource or capabilities to take this work much further. A number of studies and model upgrades are being commissioned (by DECC and CCC) and proposed (by Imperial College via SuperGen) as this report is being published. ERP will seek to support these initiatives where appropriate.
- A significant amount of new zero carbon firm capacity is essential to decarbonisation but leading technologies such as nuclear and CCS require long lead times. Therefore meeting emissions targets for 2030 requires action today to develop these options if they are to be part of the solution.
- Given that providers of ancillary services need to feel a market pull, it is recommended that policy makers in DECC and experts in National Grid consider how they can be given the financial comfort needed to underpin their development and deployment before traditional providers disappear.

The European Commission's Smart Grid Task Force has recently published an analysis of the regulations surrounding demand-side flexibility and included recommendations for policy makers and grid operators. ERP advises that some of these recommendations be examined by policy makers and National Grid for applicability across all providers to the GB system. The most important are:

- **No. 2:** Equal Access to Electricity Markets for all providers
- **No. 3:** Contractual arrangements should be simple, transparent and fair
- **No. 4:** Standardised measurement of flexibility
- **No. 12:** Incentivise grid operators to enable and use flexibility, investing for meeting 2030 targets rather than focus on short-term optimisation
- **No. 13:** Improving price signals for providers

Background

In light of the increasing penetration of variable renewables the ERP undertook to examine issues around grid flexibility and stability. A model was developed to balance not just the need for energy but also ensure the supply of services critical to the operation of the grid. This was used to produce robust modelling of a real GB system across a wide range of scenarios, supported by more stylised analysis to explore the fundamental constraints within which a secure technology mix must lie.

As well as the high level conclusions there is some guidance offered on specific topics, such as some preliminary work on storage. This work highlights a valuable and necessary approach to considering the GB system as a whole. With less focus on the specifics, the power of this is in setting the direction of travel and defining the solution space.

The Issues

If the GB system is to meet the 2030 targets for carbon reductions suggested by the CCC (50 g/kWh) or even DECC's central scenario of 100 g/kWh, there will need to be huge changes to the way electricity is generated and consumed. Even without these targets the economic pressures and the effect of EU directives will force significant change to the generation portfolio. Without remedial action, many of the changes will reduce the stability of the system:

Increased weather dependency

Inertia is reducing

Largest infeed loss is getting bigger

Traditional providers of flexibility are disappearing

Electricity Market Reform does not address stability

Fortunately many potential solutions exist for flexibility or could be brought forward in the right environment:

Flexible demand

Embedded generation

Storage

CCS

Interconnectors

New gas

New Nuclear

Experience of Other Grids

As the GB system is not unique in facing issues of integrating renewables, a brief examination of similar systems was undertaken to examine lessons-learnt. Two systems in particular were thought to be important in this respect: **Germany** because of its high penetration of renewables, and **Ireland** because of its relatively isolated position.

Germany

At the end of 2014 Germany had 36 GW of wind and 38 GW of solar, with a peak demand of over 70 GW. So at first sight it might be thought that Germany is already tackling issues associated with intermittency that the GB system will have to face if the UK also aims for significant production from renewables. However, closer examination shows us that Germany is not in the same position and the solutions currently employed there are either not possible or unpalatable for the GB system:

- Its production from wind and PV is still quite low compared to scenarios explored here
- Although well short of having surplus renewables generation it chooses to export a lot of production so that high carbon plant runs baseload
- Most of its immediate trading partners (with the exception of the small Danish system) have not yet constructed large amounts of wind and PV
- Germany benefits from being a small part of a very large synchronous system

Ireland

Unlike Germany the electricity system of Ireland and Northern Ireland is a small synchronous system with modest DC links to the GB system. Its planned renewable generation is dominated by wind, with the aim of 5-6 GW of installed capacity by 2020, against a peak demand of around 7 GW. Currently just under 3 GW are connected.

To manage this EireGrid and SONI, the system operators, ensure that total generation from non-synchronous generation (which is mostly wind) never exceeds 50% of demand. This is achieved by curtailing wind output if this limit is about to be breached.

It is unlikely that the GB system would want to adopt this early curtailment as a means of dealing with intermittency issues and this is not seen as a long term solution by the Irish system operators. Although curtailment can alleviate immediate stability or grid constraint issues, in the longer term significant levels of curtailment increase the system cost of renewables and set an artificial barrier to their penetration.

Modelling Results

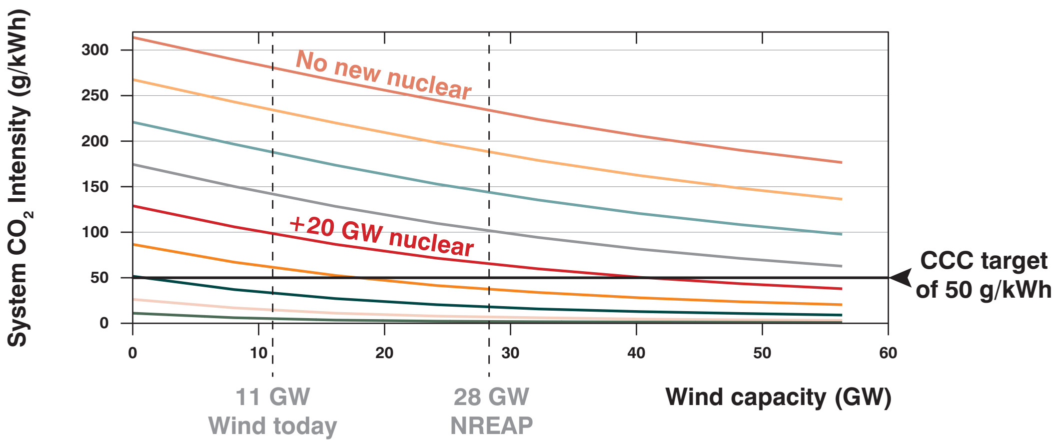
A new model, BERIC, was written by ERP to **B**alance **E**nergy, **R**eserve, **I**nertia and **C**apacity requirements.

Meeting Emission Targets with Nuclear and Wind

The scenario underpinning the CCC's 4th Carbon Budget had a decarbonisation of the grid down to 50 g/kWh. The November 2013 review confirmed that this level of decarbonisation by 2030 is on the most cost effective pathway to the 2050 target. DECC uses a central scenario that has a 2030 emissions intensity of 100 g/kWh. These two levels are illustrated in the results to demonstrate the likely range of outcomes.

The figure shows how the carbon intensity varies with addition of wind to the base scenario, with differing levels of nuclear capacity. For the lower penetration levels the carbon free wind generation displaces emissions from gas plant and intensity falls, however, its effectiveness at abatement declines as more is added. Examination of the schedule shows that as wind is added it is displacing progressively lower carbon plant eventually causing significant levels of curtailment of its own output or that of other zero carbon plant.

The curvature of the plot clearly shows that the effectiveness of additional wind at decarbonising the system is strongly dependent on the existing build. In fact the modelling shows that the economic value of adding any of the low carbon technologies to the system is also strongly dependent on the existing grid mix in a non-linear manner. Therefore a technology cannot be characterised by a single number such as Levelised Cost of Energy (LCOE) but must be evaluated using a holistic approach taking account of the full cost of balancing the system.



Emissions as a function of wind and nuclear capacity

The series of lower lines represents the addition of 5 GW increments of nuclear capacity. The effectiveness of this is clear, showing that 20-25 GW of nuclear alongside the NREAP target for wind (or 30 GW of nuclear alone) will achieve the CCC's 50 g/kWh decarbonisation target. Although this set of scenarios explored differing levels of nuclear, similar results would be obtained with any Zero Carbon Firm (ZCF) capacity so long as it emits no CO_2 and provides capacity that is (on a fleet basis) as reliable as fossil plant. This could for example be CCS plant that burns sufficient biomass to offset the residual emissions or an unabated plant that burns biomass with no attributable emissions.

Checking BERIC with Merit Order Calculations

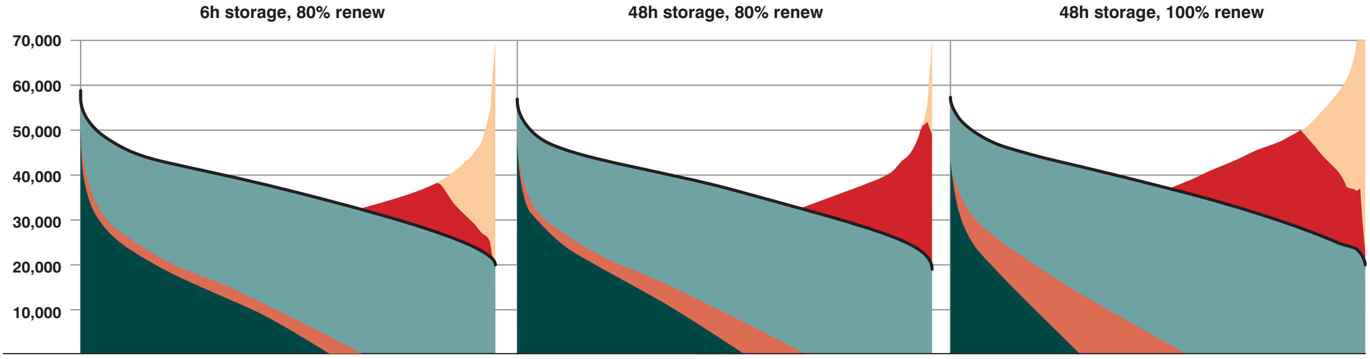
To check these modelling conclusions, and to examine the effects behind them, some simplified merit order calculations were performed. The supply side was simplified to just three types of plant, namely:

- weather dependent renewables (an aggregate of PV, onshore and offshore wind that minimised curtailment),
- Zero Carbon Firm (ZCF), and
- unabated gas (representing a 25:75 mix of peaking and high efficiency plant).

For each half hour these were stacked, in that merit order, to meet demand. Three scenarios were constructed: one that was renewables only, one that was ZCF only and one that was an equal mix of renewables and ZCF in terms of energy available.

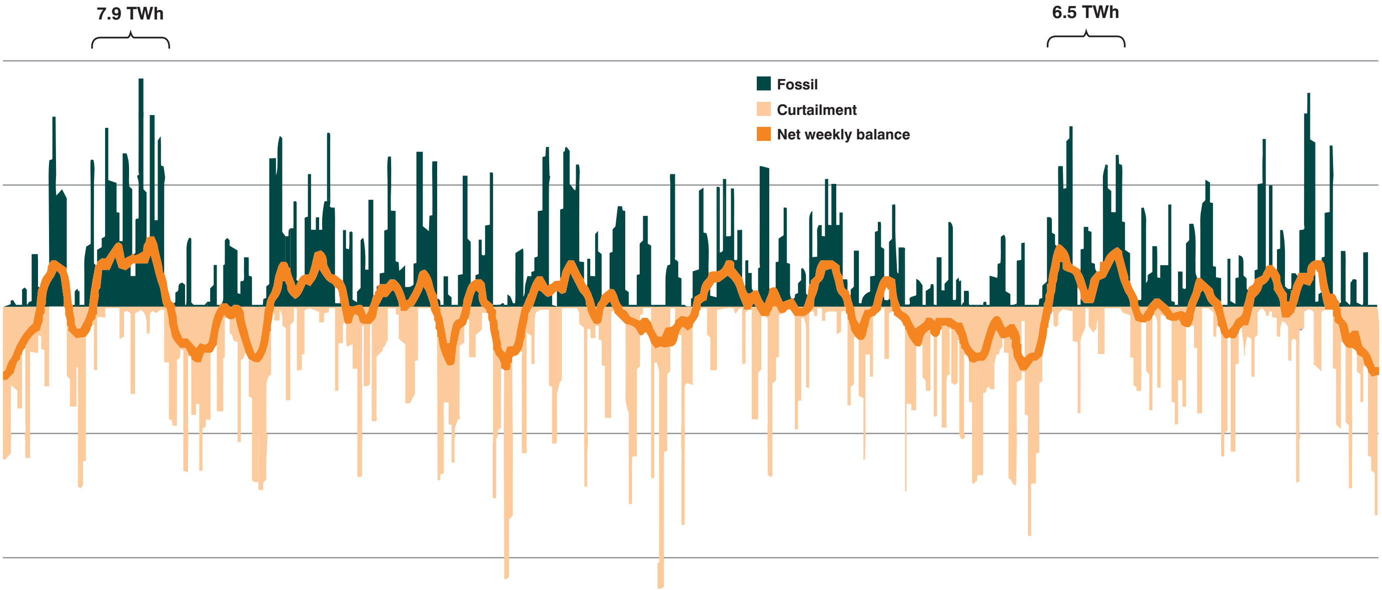
The Value of Storage in Solving Curtailment Issues

A storage capacity of 30 GW was added, representing a ten-fold increase on GB's current pump storage capacity but a larger storage volume was examined from 6 hour's generation (similar to today's storage that cycles on a daily basis) to 48 hours.



Showing effect of storage in utilising excess zero carbon generation

The results are illustrated above in the traditional manner of a load duration curve based on 2012 data. The solid line represents demand throughout the year sorted such that peak demand is on the left and minimum demand on the right. The light green area represents the energy delivered by variable renewables, orange is from ZCF with the dark green representing unabated gas. The dark red area illustrates the curtailed energy that now goes into storage, and storage generation displaces gas as represented by the pale red area. With the 30 GW of 6h storage then nearly half the curtailed energy is utilised and the generation reduces emissions by 16 g/kWh to 112 g/kWh. Increasing the storage volume to cover 48 hours of generation improves the effectiveness of the storage significantly, emissions fall to 98 g/kWh and curtailed energy falls to just 1% of total energy demand. Pushing the variable renewables build so its potential output matches demand in the final chart shows that although the storage is well used there is still a significant spill (8% of generation) and fossil is required to fill 12% of demand. This scenario just meets the 50g/kWh target, the remaining emissions coming from a "stubborn triangle" at the bottom left of the load duration curve that is difficult to reach.



Daily energies across the year showing two periods of high fossil use

A second consideration is the need to meet demand, i.e. system security. Of particular note here are periods of low renewable output where storage could potentially fill the gap. The two most challenging periods are marked on the chart. Each lasts 3 weeks and has a net shortfall of 6-8TWh. Filling this gap represents a serious challenge for storage - current pumped hydro on the GB system can hold less than 0.03 TWh so is clearly not the right technology and other storage technologies seem a long way from delivering this volume.

Demand Side Management

The 8 TWh gap is not going to be solved through DSM as it represents an average reduction of 15 GW for 3 weeks. There is little domestic activity that can be delayed that long and the reduction needed exceeds average industrial demand.

Interconnection

Interconnectors could benefit the GB system by connecting it to markets with different weather influences and so take excess generation at times of GB surplus and return carbon free generation at times of low renewable output. However these interconnected markets would not always be in the right state to do this – for instance when similar weather was being experienced in the neighbouring markets that had installed similar renewable energy technologies. The only exception might be for an interconnection to a market such as NordPool that has significant reservoir hydro. In this case, if NordPool ran its hydro plant for the benefit of the GB system the 8 TWh needed to fill the low wind gaps could probably be accommodated over a 20 GW interconnector. In practice though, the UK may find other EU nations also wanting to use NordPool's balancing capabilities and some, unlike the UK, are already connected. It is likely then that interconnection can help, especially to NordPool, but is unlikely to provide a complete solution as other markets compete for the same resources.

Summary of Load Duration Calculations

Therefore with the diminishing returns of adding more variable renewables, and the need to cover 2-3 week periods of low renewable output, **a complete decarbonisation is going to need a significant amount of firm low carbon capacity.**

Key Observations

- Hitting 50 g/kWh drives the need to meet the vast majority of residual demand (after allowing for variable renewable generation) in a low carbon manner. Even acknowledging the possible contribution of DSM, interconnectors and storage to firming up weather dependent renewables, a deep decarbonisation of the grid will need a significant penetration of zero carbon firm capacity. In ERP's modelling a minimum of 13 GW of new zero carbon firm capacity was required to meet 50 g/kWh. Given the long timescales for introducing these technologies there is a pressing need to prioritise their introduction if carbon reduction targets are to be met.

- Of the issues examined it is rare for lack of inertia to be a biting constraint, the recent changes to disconnection settings for distributed generation will allow the system to tolerate lower values of inertia than at present. However modelling the requirements for frequency response and fast reserve make a significant difference to total system cost and especially to emissions, and so cannot be ignored. The need for frequency response is driven by issues other than the technology mix, and so is relatively easy to model, but the need for fast reserve and STOR are most critical and dependent on technology choice.

- Using DECC's cost estimates the differences in economic value to the system between the key options examined (nuclear, gas-CCS and onshore wind) are much smaller than the margin of error estimating those costs. Therefore it's difficult to claim any one of these is the optimal solution to progress grid decarbonisation. Furthermore the value to the system is highly dependent on the technology mix on the system, and the effect of diminishing returns reduces the value of all technologies as they are added, but especially so of variable renewables which generate an increasing proportion at times of surplus energy.

- Technologies like DSM/flexibly operated interconnectors and new storage will help optimise the system, especially one with a high penetration of PV and wind, but will probably not bring fundamental changes to the ultimate solution. In helping to reduce curtailment from a good balance of wind and PV there appears to be little value to extending storage capacities beyond a few days.

- Germany's Energiewende does not provide a good example for the GB system which is unable to rely on being embedded within a much larger system. Germany's current model phasing out much of its zero carbon firm capacity in favour of high carbon inflexible lignite also runs directly against all the recommendations here.

- The implication of valuing firm capacity and ancillary services is that it would be helpful to consider changing the retail market pricing structure to reflect the actual costs.

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