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The characteristics of electricity storage, renewables and markets

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ABSTRACT

This paper accepts the widespread view that as electricity generation systems transition towards a greater proportion of renewables provision, there will be an increasing need for storage facilities. However, it differs from most such studies in contrasting the private incentives of a storage operator with the public desirability of bulk storage. A key factor in the context of a market such as Britain, where renewable energy largely means wind generation, is the nature of wind generation itself. The problem of wind's high variance and intermittent nature is explored. It is argued that not only is there a missing money and a missing market issue in providing secure energy supplies, there is also a missing informational issue. A key opportunity for new storage is participation in a capacity market, if the setting is right.

1. Introduction

This paper examines aspects of energy storage from the viewpoint both of opportunities for private firms and what would be socially desirable. The context in which this is set is important. Claims about the generation cost per MW h of renewable-generated electricity being competitive with more conventional power plants are commonly made. In Britain, there is a plausible argument that the levelised cost per MW h of onshore wind is comparable with the price the Government has agreed to pay for a new nuclear plant under development (DECC, 2013, chart 3). Of course these costs are not equivalent in terms of supplying power as required, since both have limitations. Solar power is intermittent; wind power is both intermittent and has an extreme and time-correlated variance. Nuclear power, on the other hand, is inflexible. Thus both renewables and nuclear power require additional facilities to be present in the electricity delivery system to facilitate correspondence between demand and supply. Traditionally, these have taken the form of more flexible fossil-fuelled generating plant on grid. However, if the presence of renewables increases, and at the same time, the role of fossil-fuelled generators decreases due to retirement of ageing or overly polluting plant, additional measures will be required. One obvious additional facility is increased energy storage (Denholm et al., 2010; European Commission Directorate General for Energy, undated; Greve and Pollitt, 2016).

The main novelty in this paper lies in the comparative analysis of market-based and socially desirable storage (largely ignoring power quality operations such as frequency regulation that take place very near to real time). The main finding in relation to market arbitrage-based storage is that diurnal storage is currently the obvious source of profit in Britain, given the large diurnal price differences, the relatively small price differences over days, and the unpredictability of wind over more than a short period. Such arbitrage activity is most suited to storage over no more than a few hours, implying the leading technologies are likely to be heat storage or compressed air technologies (on which see later). However, there are clear social benefits to longer term storage based upon saving peak generation and a reduced need to curtail renewables, which point more towards compressed air energy storage. But these benefits, we argue, would not be captured by the store under arbitrage mechanisms, because they require look-ahead times much longer than available given current weather forecasting and market pricing models that currently do not exist. There is extremely limited information, and missing markets.

This modifies the emphasis on market issues compared with Newbery (2016), who points to the problem of missing markets, but also to missing money. We add to these the issue of missing information, which renders the development of some markets extremely difficult. The essential difference between missing markets and missing information is the following. Missing markets are those that could exist, or would exist, under an alternative framework, for example given a different regulatory structure. Missing information is something that prevents a market existing, because there is scant or no information on which to form expectations of the future and hence to formulate prices. For example, if there is no way of knowing whether it will be extremely windy or extremely calm next week, expectations

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cannot be formed.

We further argue that interconnectors and smart metering, alternative mechanisms for bringing demand and supply into line, are for different reasons not obviously suited to these longer-term issues. Moreover, it is unlikely that prices are able to provide enough of a signal to storage operators looking to longer-term storage. Therefore, the obvious alternative to attract longer-term storage appears to be a capacity mechanism. But in turn this relies on the treatment of storage relative to other forms of capacity, given that storage is currently viewed both as a consumer and a generator and hence pays charges related to both, and also is limited in that it cannot commit to an indefinite supply time. The paper sets out some of these arguments. Our context is Great Britain, but there are some parallels in other countries. However, the requirements for storage will differ between countries somewhat, dependent on the make-up of renewable generation and the pattern of demand across those countries.

The paper proceeds with a brief resume of storage technologies and discusses the characteristics of renewables, proceeds in Section 3 to consider the role of electricity pricing and arbitrage, then subsequently discusses the differences between private and social benefits to storage in the context of uncertainty about the amount of renewable power in Section 4, goes on to consider alternative market forms in the light of this in Section 5, and finally discusses the policy implications of the analysis in Section 6.

2. Storage technologies and characteristics of renewables

There is a widespread view (e.g. Denholm et al., 2010; Evans et al., 2012) that as countries increase the role of renewable resources, principally wind and solar, in electricity generation, storage will become more important in the role of balancing supply and demand for electricity. The operative issues are how much of which type will be required, what benefits could it bring, and how will it make money. What storage is "required" and how it makes money are separate issues.[2] This links with the proposed technology employed to "store" electricity and the institutional framework into which it slots.

The electricity industry in England and Wales (and to a lesser extent, Scotland) is extremely vertically disintegrated so far as the role of the grid operator is concerned. Specifically, the grid operator cannot own storage facilities, a situation which contrasts with that in Italy, for example, where Terna is active in developing storage. Moreover, there is no equivalent of the regulated electricity utility, as exists in large parts of the USA. Therefore, it is not possible for the grid operator (nor to a large extent the distribution companies) directly to internalise the benefits of storage that accrue to themselves. Nor has investment in storage been mandated, as it has for example in California. In Britain, external market mechanisms through contracts with National Grid, if present, are the method by storage may be incentivised. More generally, many systems including the British electricity system, suffer from storage not being accommodated within the standard framework of generator or supplier; indeed it is commonly treated as both, rather than as a facilitator for smoothing capacity issues. The role of storage in particular of batteries in primary and secondary (within seconds) frequency control is recognised, as also for example in Germany (Energy Storage Update, 2015), but very little attention has been paid to longer-term storage in other technologies such as CAES.

Batteries are good at fast reaction but short duration requirements, and so are best suited to quality maintenance such as frequency regulation- for example in Britain, plans are under development to tender for facilities capable of reaching full power in less than one second to be sustained for some minutes and this is attracting interest from battery storage. Anything over a few minutes is not suited to the use of batteries, which at least currently have very limited energy capacity. Hydroelectric storage has the capability to supply electricity at significant rates over a relatively long period, and it can reach maximum power in a matter of seconds, but it is limited in the extent to which it can be constructed economically, because it relies on the existing geography of the country.

Heat-based storage (e g HTTP; High Temperature Thermal Power) and compressed air electricity storage (CAES) have the additional potential to store electricity to be delivered for a period of a few hours to over several days. It is these latter two that are most related to the subject of this paper, given the diurnal pattern of prices. Heat-based storage has relatively low fixed cost but high operating cost compared with CAES and so is best employed for relatively shorter periods. However, it should be emphasised that fixed costs and running costs for each of these technologies, particularly the newer ones, are subject to significant uncertainty and a degree of optimism on the part of their proponents, together with a certain amount of commercial secrecy. Therefore it does not seem reasonable to give more than these indications regarding the relative cost characteristics of the various storage technologies.[3]

Implicitly, the discussion below is framed with CAES-based storage in mind, although it can be applied to other technologies. Therefore it may be useful to explain the technology briefly. CAES involves compressing air into a store, for example a cavern, using electrically-driven pumps. When power is needed, the operation goes into reverse; air released from the cavern drives turbines which produce electricity.[4]

The key intermittent renewable resources being employed to generate electricity at grid scale in Britain are wind power, solar power and prospectively tidal power.[5] None of these is biddable in the way that conventional combustion power plant is. Tidal power is intermittent but almost completely predictable. Solar power is intermittent but relatively predictable. In particular, we can predict that it will not be available at night! Wind is intermittent but arguably relatively unpredictable except in the short run, and erratic. Wind, significant both onshore and offshore, is by far the largest proportion of generation in the UK under current circumstances, and is likely to remain so. Hence this is the prime focus of the analysis.

For the purposes of analysis, we use data for Great Britain from the period end-November 2014 to end- September 2015. The start date is determined by availability of data for wind forecasts, which have traditionally only been displayed temporarily on the BM Reports website provided by Elexon. Since end-November 2014, the Gridwatch site has been recording the data feed including wind forecasts.[6] In illustrating features of these data, we sometimes choose shorter periods for clarity of presentation, but the main analysis is done using the 10 month period.

Table 1 characterises the wind generation pattern. Whilst on average over 2.5 GW are being generated currently, the variance is very large, so that on a high proportion of occasions less than 1 GW is being generated. In Britain, and many other countries, one characteristic is that the weather can be calm for several days in a row, so that wind generation

[2] Much of the literature's focus (see e.g. Cavallo, 2007) has been on system requirements, without regard to how storage will be provided commercially. From the opposite standpoint, Zafirakis et al. (2017) examine the potential commercial role of arbitrage, without regard to its social desirability.

[3] More detailed information regarding comparative capital costs are provided in Evans et al. (2012), but recent attempts to construct commercial HTTP plant in Britain have run into problems suggestive of over-optimistic assumptions on costs.

[4] There are two variants: adiabatic CAES requires no additional fuel, whilst existing facilities such as at Huntorf in Germany, involve using the air in a gas turbine; of course air when compressed warms and when decompressed cools, and in both cases the technical design needs to accommodate this.

[5] Other renewable sources include biomass and run-of-river plant (of which there is very little in Britain), but in any case these are more controllable and therefore do not lead to the problems discussed in this paper. There are also relatively limited storage facilities based on hydro-electric plant, because the terrain is largely unsuitable.

[6] Its recording of other variables has a longer history. Intending users of this site should note that the series do contain several unmarked gaps, mostly of a few hours' duration, meaning care needs to be taken in creating a consistent continuous time series.