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Developing pathways for energy storage in the UK using a coevolutionary framework

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HIGHLIGHTS

- Energy storage can play a significant role in a low carbon UK energy system.
- Changes in the selection environment will impact its deployment.
- Several different deployment pathways are possible.
- Its precise role is still subject to considerable uncertainty.

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ABSTRACT

A number of recent techno-economic studies have shown that energy storage could offer significant benefits to a low-carbon UK energy system as it faces increased challenges in matching supply and demand. However, the majority of this work has not investigated the real-world issues affecting the widespread deployment of storage. This paper is designed to address this gap by drawing on the systems innovation and socio-technical transitions literature to identify some of the most important contextual factors which are likely to influence storage deployment. Specifically it uses a coevolutionary framework to examine how changes in ecosystems, user practices, business strategies, institutions and technologies are creating a new selection environment and potentially opening up the energy system to new variations of storage for both electricity and heat. The analysis shows how these different dimensions of the energy regime can coevolve in mutually reinforcing ways to create alternative pathways for the energy system which in turn have different flexibility requirements and imply different roles for storage technologies. Using this framework three pathways are developed – user led, decentralised and centralised – which illustrate potential long-term trajectories for energy storage technologies in a low-carbon energy system.

1. Introduction

The United Kingdom (UK) has committed to reduce its greenhouse gas emissions so that, by 2050, emissions are at least 80% below 1990 levels (Great Britain, 2008). This goal will require significant changes to the way in which energy is produced and used - including a huge increase in the use of renewable energy, a substantial rise in the demand for electricity to provide heat and transport and sustained improvements in energy efficiency (HM Government, 2011). Such developments are likely to pose significant challenges for the energy system in matching supply and demand, and so could create substantial opportunities for the deployment of additional electricity and heat storage. For instance, a recent assessment by the Low Carbon Innovation Coordination Group examined the value of innovation in energy storage to decarbonising the UK energy system. It concluded that the deployment of energy storage technologies has the potential to yield total system cost savings of between £2–10 billion over the period to 2050, while creating a market worth between £3 bn and £26 bn over the same period (Low Carbon Innovation Coordination Group, 2012).

Currently, most of the energy storage capacity in the UK energy system is provided by stocks of fossil fuels. Wilson et al. (2010) estimated the electricity that could be generated from UK stocks of coal and gas destined for the power sector was around 30,000 GW h

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and 7000 GW h respectively. In contrast, electricity and heat storage is several orders of magnitude lower. Bulk electricity storage – provided by pumped hydroelectric plants – totals only 28 GW h. There are also a few smaller electricity storage facilities connected to the distribution system, most of which are demonstration projects involving various types of battery. Heat storage is largely distributed and mostly at an individual building scale and is either provided by hot water cylinders (installed in around 14 million homes, giving a maximum storage capacity of around 80 GW h) or by electrical storage heaters (which are the main source of heating in 1.6 million dwellings). A number of district heating schemes in the UK also have hot water storage associated with them.

Despite the likely challenges in matching supply and demand in a low-carbon future, storage has not been well represented in the majority of future scenarios for the UK energy system (ERP, 2011). As a result, there has been little detailed analysis of the potential role of energy storage in helping the UK to achieve deep emission reductions or investigation of the range of factors that could impact its deployment prospects. To the extent that current scenarios consider energy storage at all, they largely focus on the role of bulk, centralised electricity storage, such as pumped hydroelectric storage – with little, if any, consideration for heat storage (Committee on Climate Change, 2008; HM Government, 2011).

Until recently, most energy storage research has focused on developing a range of technologies with different characteristics (Baker, 2008; Chen et al., 2009; Hall and Bain, 2008), rather than examining how different storage technologies might operate in a low-carbon context and their value or means of integration into energy systems. In the case of the UK energy system, notable exceptions include an early techno-economic analysis by UMIST for the Department of Trade and Industry (DTI, 2004) and more recent work on the role of storage by Grünewald et al. (2011) and Wilson et al. (2011). One of the few studies to look at the broader regulatory and policy issues is ERP (2011).

However, over the last year there has been a growing interest in the role that energy storage could play in a low-carbon energy system. A recent major techno-economic analysis commissioned by the Carbon Trust (Strbac et al., 2012b) concluded that energy storage technologies could have significant value to a low-carbon UK energy system, particularly one with a large contribution of renewable generation. Furthermore it found that distributed storage could offer higher value to the electricity system than bulk storage, due to distribution network savings.

However, energy storage is not the only solution to meeting the challenges posed by a low-carbon energy system. Back-up fossil generation capacity, interconnectors and flexible demand, amongst others, can also play a role. The competition and interaction between these alternative balancing technologies has been explored in a recent report (Strbac et al., 2012a) for the Department of Energy and Climate Change (DECC). This study found that the efficient amount of distributed storage is highly sensitive to its cost and the level of demand side response in the system; on the other hand it is not sensitive to the level of interconnection and flexible generation.

These recent modelling analyses take a 'whole systems' perspective and assume a perfectly competitive electricity market. They therefore do not take into account many of the real-world issues which affect storage deployment, such as the structure of electricity markets and regulations and the interaction of users with domestic scale storage applications. Some of these issues are explored by Grünewald et al. (2012) through combining stakeholder interviews and socio-technical transitions theory. They find that distributed electricity storage currently faces a number of challenges associated with technology lock-in and path dependency resulting from poor alignment of the current regulatory regimes governing generation, networks and consumption with the requirements for storage.

Our paper builds on, and extends, the arguments presented by Grünewald et al. (2012) by bringing a comprehensive whole systems understanding of the factors that impact energy storage, including the role of technology, institutions, business practices and users. This is achieved by using a coevolutionary framework (Foxon, 2011) to integrate these different dimensions into a number of long-term pathways for both electricity and heat storage, so identifying future opportunities and challenges for this group of technologies. In Section 2 we outline this framework, which is based on insights from the innovation studies and socio-technical transitions literatures, and explain how we have applied it to examine energy storage in the UK. Section 3 then reviews the key contextual factors that are likely to influence storage deployment in the transition to a low-carbon energy system, drawing on the output of a workshop which included key industry stakeholders, academics and policy-makers. Following this, Section 4 presents our illustrative pathways for energy storage in the UK, which are based on different forms of coevolutionary interaction between technology, institutions, business practices and users. Section 5 then analyses the energy storage pathways in more detail, highlighting potential risks that may lead to 'branching points' (Foxon et al., 2013) along the pathways. Finally, in Section 6 we present our conclusions, including some implications of our findings for policy.

2. Analytical framework and methods

In this section we draw from the extensive literature on system innovation and socio-technical transitions to frame and analyse prospective energy storage pathways. A key motivation in doing so was to move beyond much of the existing analysis which tends to treat storage as individual technologies with little consideration of how different applications might operate in a wider energy system context, and to try to capture the wider social and institutional factors which might influence storage in a low-carbon energy future.

2.1. A systems perspective on energy storage deployment

Innovation processes in large scale systems such as energy supply have a different character than conventional product based sectors. The complex and interconnected nature of infrastructure and its public good character means that a wide range of actors and institutions – including government, regulators, and lobby groups – influence technical change in these sectors. In our analysis of energy storage innovation and deployment we must therefore look beyond the traditional producer–user relationships. While cost and performance of technologies are of course important, the institutional environment, governance structures and the willingness of users to engage with new technologies will be a key factor in influencing which innovations emerge and the degree to which they are deployed across a system.

Recognising this, recent studies which adopt a socio-technical transitions perspective have emphasised that the diffusion of individual technologies, such as energy storage, cannot be considered in isolation, but rather occur in the context of a wider system or regime (Foxon et al., 2005; Verbong and Geels, 2007). Regimes are composed of '(networks of) actors (individuals, firms, and other organisations, collective actors) and institutions (societal and technical norms, regulations, standards of good practice) as well as material artefacts and knowledge' (Markard et al., 2012: p.956) and provide structure and stability to large scale and complex socio-technical systems. Transitions theory argues that regimes act as strong selection environments for a variety of technologies and practices, those which align well are likely to be adopted whereas