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Innovation in regulated electricity distribution networks: A review of the effectiveness of Great Britain's Low Carbon Networks Fund

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ABSTRACT

Introduced in 2010, the Low Carbon Networks Fund (LCNF) was a major development in the regulatory regime for electricity distribution networks in Great Britain, yet evaluation of its design and implementation has been limited. This paper examines the type and quality of innovation arising from the LCNF. Novel frameworks for assessing innovation project activity and learning are presented and results from their application to the LCNF are discussed. Reduction of uncertainty through the production of high quality evidence is argued to be the primary purpose of innovation project funding support. The analysis of LCNF project activity finds a step change in Research Development & Demonstration (RD&D) spend and stakeholder engagement by network licensees in Britain; however, the innovation observed was considered to be conservative and incremental in nature. It was found that the LCNF lacked a strategic approach to targeted learning and the reduction of uncertainty for innovation priority areas. Project learning outputs were contradictory and inconclusive for several innovations. Strategic learning should be a core part of policy makers' design of innovation funding mechanisms for energy technology, and a framework for shaping, capturing and assessing the learning outputs of funded innovation projects is essential.

1. Introduction

The landmark Paris Climate Agreement was signed in December 2015 by 195 countries at the 21st Conference of the Parties (COP21) obligating all parties to limit global temperature rise to less than 2 °C above pre-industrial levels (UNFCCC, 2016). World leaders at Paris emphasised the critical role energy technology innovation will play in achieving this goal leading to the establishment of Mission Innovation (2016): an agreement between 21 regions to double their clean energy research, development and demonstration (RD&D) investment by 2021. All but one of the partners has listed electricity grid innovation as a priority area.

The United Kingdom of Great Britain and Northern Ireland is one such country that has situated electricity network innovation at the centre of its decarbonisation strategy (DECC, 2015). Traditionally the electricity networks of Great Britain (GB) have facilitated the transmission and distribution of electricity from large-scale centralised power stations, with highly predictable baseline supply, to consumers with well understood patterns of aggregated demand. However, recent years have seen a shift towards the deployment of intermittent electricity generation and the move to decentralised generation from a combination of consumers and smaller-scale generators; a growing emphasis on the electrification of heat and transport also significantly changes the nature of demand (National Grid, 2016; Committee on Climate Change, 2016).

Historically, in the era since privatisation, the electricity distribution networks of GB were not conceived of as a hotbed of innovation (Jamasb and Pollitt, 2015). However, following a combination of landmark climate change legislation and low-carbon energy policies (HMSO, 2008, 2009b), the GB gas and electricity markets regulator, Ofgem, has recently sought to stimulate innovation via its £500 m Low Carbon Networks Fund (LCNF) (Ofgem, 2010a).

Consultants commissioned by Ofgem published a review of LCNF in 2016 that aimed "to understand the extent to which the aims of the LCNF have been met in supporting the future development of innovation in the industry". This concentrated on providing an assessment of the costs and benefits of innovation, concluding that benefits to the time of publication ran to approximately one third of the cost of the innovation projects and estimating that future net-benefit would run to between 4.5 and 6.5 times the cost of funding the scheme (Poyry, 2016). However, characterising the *types* of innovation the LCNF has facilitated at a programme level and assessing the *quality of the learning* achieved is essential if lessons are to be learned about how best to support electricity network innovation via government policy and, more broadly, about best-practice in operation, planning, management and regulation of the electricity system. Consequently, this paper seeks to provide policy makers with answers to all the

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following questions:

- What level of financial innovation support did the LCNF provide?
- What number and type of innovation projects did the LCNF support?
- What observed quality of innovation and learning has been generated by the LCNF?
- What lessons can be learnt from the LCNF about how best to support electricity network innovation in the future both in the UK and internationally?

The paper is structured as follows. Section 2 presents a review of literature relating to regulation and innovation in electricity network industries. Section 3 outlines the history of the management of GB's electricity network and policy-led initiatives to promote network innovation. Section 4 reviews recent studies examining the effectiveness of the LCNF. Section 5 presents the methodology for reviewing the type and quality of the LCNF's innovation outputs. Section 6 presents the results of the study. Sections 7 and 8 discuss the importance of these findings and the resulting energy policy recommendations. Section 9 presents the study's conclusions.

2. Regulation and innovation of electricity network industries

This section outlines the core characteristics of electricity networks and discusses the importance of state led regulation in order to promote innovation.

2.1. Characterising the electricity network sector as a network industry

Electricity distribution networks are an example of a *network industry*, which has been defined in (Bogaert, 2006, p. 20) as one that "move[s] people, products or information from one place to another via a physical network of a certain kind". The benefits of electricity networks are that: they allow generation resources to be located away from where energy is used so enabling a reduction in the cost of access to the primary fuel and minimisation of the impact of the conversion process on population centres; and they permit a pooling of resources so that provision of reserve generation to satisfy reliability of supply standards can be achieved at least cost. In liberalised electricity supply industries, interconnected networks also facilitate competition between generation resources.

According to Bogaert (2006), network industries exhibit a number of special characteristics that shape both the way they function and, in turn, how they are managed. The first is that network industries typically provide *public services of national interest* that make a critical contribution to both economic growth and social welfare. Consequently, they are often referred to as critical infrastructures that are integral to national security, meaning their proper functioning is of key national significance. This requires measures capable of protecting a combination of security *and* affordability of supply (UKRN, 2015).

The second is that network industries are affected by *positive feedbacks*, most notably network externalities or increasing returns to scale, which means that the "value to a buyer of an extra unit is higher when more units are sold, everything else being equal" (Economides, 2006). For example, in the case of electricity networks, consumers are able to source electricity from a larger number of generators, theoretically increasing competition and security of supply. They are also influenced by other feedbacks such as the economies of scale (Haas, 2006), where unit costs decline with increasing output. These two positive feedbacks coupled with economic factors such as high sunk costs in network infrastructure (Arthur, 1994) and the power wielded by incumbent firms that have a vested interest in the status quo (North, 1990; Pierson, 2000) can contribute to these network industries becoming 'locked-in' and resistant to the development and adoption of innovation.

The third is that network industries are typically subject to *natural monopolies*, a consequence of the substantial sunken capital investments and economies of scale noted above, meaning it is generally uneconomic to duplicate rival networks leading to the formation of a natural monopoly (Bogaert, 2006; UKRN, 2015).

Finally, network industries are characterised by *complementary nodes and branches*, meaning that networks are made up of physically distinct but mutually dependent and inter-connected components (Economides, 2006). The interconnected nature of networks poses specific challenges, not least the potential for cascading effects, where failure in one component can result in knock-on effects. In the worst case, this can lead to wide-spread disruption affecting the whole system. For example, blackouts resulting from power network components failures, such as the one that affected 50 million North Americans on the 14th August 2003 (Hines et al., 2009). System operators are therefore faced with a particular kind of risk where the impacts of unplanned events can be very large indeed (CIGRE, 2010).

Overarching characteristics of energy systems are: (1) the *capital intensiveness* of energy technology investments; and (2) the *longevity of capital stock* (Grubler et al., 2012). The first relates to the energy sector being "characterised by high upfront costs, a high degree of specificity of infrastructure, long payback periods, and strong exposure to financial risk stranded assets (IEA, 2003)" (Grubler et al., 2012 p. 1674). The second underlines how energy technology and infrastructure stock typically lasts for a longer period of time compared with many other sectors, meaning the turnover of stock is slower. This longevity and the uncertainty of future need gives rise to the risk of stranding of assets and, in turn, can instil a highly conservative and risk-adverse investment culture (IRENA, 2017).

2.2. Stimulating innovation in electricity networks via regulation

Innovation is widely considered to stem from a bid to capture a larger market share by improving consumer value-for-money, either by improving customer satisfaction and/or reducing a customer's costs (Aghion and Griffith, 2005). Not only can this provide a direct benefit for the customer *and* the provider but also wider benefits for society if the innovation has a strong degree of social and environmental value, often referred to as a *triple bottom line* (Elkington, 1997). However, network industries such as electricity networks represent a special challenge with regard to innovation. Firstly, as natural monopolies, market forces are considered insufficient to cultivate innovation via competition (Economides, 2006; European Commission, 2013). Without the threat of competing firms capturing market share, "a firm with significant market power does not naturally face the same pressure or incentives to reduce costs or develop new services" (UKRN, 2015). Secondly, given network industries' predisposition to lock-in effects they tend to be slow to change and often resistant to the development and adoption of new innovations (Grubler et al., 2012). In this context "enabling the appropriate level of innovation is a particular challenge" (UKRN, 2015) in network industries like the electricity sector.

The particular characteristics of network industries have led to state intervention, commonly in the form of ex-ante regulation (where a regulatory determination constraining maximum prices is made upfront) and/or ex-post competition enforcement (where retrospective review and adjustment of revenues is undertaken) (European Commission, 2013). Regulation coordinated by an independent regulator has also been proposed in order to stimulate innovation by replicating the conditions necessary to promote competition, whilst simultaneously safeguarding the functionality of the network and the interests of both providers and consumers (European Commission, 2013; UKRN, 2015).

Stimulating competition and innovation through regulation has, however, been criticised for inadvertently stifling innovation (UKRN, 2015). This is largely due to the prescriptive nature of regulation, in particular price controls, which can constrain the scope of technology and business model experimentation (UKRN, 2015). Consequently, an alternative approach has been to include *stimulus packages*. These packages are typically "funded through companies' existing revenue mechanisms but with additional requirements or conditions attached to the specific elements of innovation funding" (UKRN, 2015). They tend to be put in place by regulators where innovation may yield a strong