Frame, Damien and Hannon, Matthew and Bell, Keith and McArthur, Stephen (2018) Innovation in regulated electricity distribution networks : a review of the effectiveness of Great Britain's low carbon network fund. Energy Policy, 118. pp. 121-132. ISSN 0301-4215 , http://dx.doi.org/10.1016/j.enpol.2018.02.033

Energy Policy 118 (2018) 121–132

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

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

Damien Frame[a,*], Matthew Hannon[b], Keith Bell[a], Stephen McArthur[a]

[a] Department of Electronic and Electrical Engineering, University of Strathclyde, 99 George Street, Glasgow G1 1RD, UK
[b] Hunter Centre for Entrepreneurship, Strathclyde Business School, University of Strathclyde, Glasgow G4 0GE, UK

ARTICLE INFO

Keywords:
Distribution Network Operators
Innovation
Electricity networks
Research, development and demonstration

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*

* Corresponding author.
E-mail address: damien.frame@strath.ac.uk (D. Frame).

https://doi.org/10.1016/j.enpol.2018.02.033
Received 31 July 2017; Received in revised form 8 February 2018; Accepted 18 February 2018

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 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 societal and/or environmental benefit but not necessarily a corresponding commercial benefit (UKRN, 2015), often linked to the network industry operating as a natural monopoly and having its income tightly regulated. This approach has recently been applied in the UK energy sector and this paper assesses both its characteristics and effectiveness in the following sections.

3. Brief history of GB electricity distribution network innovation support

To establish the context within which the LCNF was conceived and introduced, the history of GB electricity industry management and innovation support is reviewed in this section.

3.1. Pre-1989: nationalisation

The electricity industry structure in Britain was nationalised in 1957 (HMSO, 1957). It consisted at this time of the Central Electricity Generation Board (CEGB), responsible for generation and transmission in England and Wales, 12 regional Area Electricity Boards responsible for distribution and supply in England and Wales and the Electricity Council as an overseeing body. In Scotland, generation, transmission, distribution and supply were all carried out by two regional vertically integrated companies. RD&D was relatively well funded during this period as the CEGB maintained a wide portfolio of power systems related research with three dedicated R&D labs and an annual total budget rising steadily through the 1970s to reach £64 m by the early 1980s (Littler, 1980).

3.2. 1989–2008: privatisation and liberalisation

The Electricity Act 1989 commenced a process of privatisation and unbundling of the electricity system in Great Britain (HMSO, 1989). The resulting system was comprised of separate licensed suppliers, generators, transmission system operators and DNOs, regulated by the Office of the Gas and Electricity Markets Authority, Ofgem (HMSO, 2000). An *ex-ante* regulation model was implemented, with prices capped for 5 year periods and, under the RPI-X price control, linked to the Retail Price Index (RPI) and an operational efficiency target set by the regulator (X). During the first three price control periods (1990–2005) annual RD&D expenditure by DNOs declined steadily to a low point of just £1 million by 2003/4 (Jamasb and Pollitt, 2015). According to Bolton and Foxon (2010), during the period from privatisation to the early 2000s, "the role of regulation was not to promote innovation or favour particular technologies or methods; the focus was on reducing costs and promoting short run efficiencies" (p. 14).

Moving into the fourth price control period (2005–2010), the energy policy context in GB was characterised by a growing emphasis on carbon reduction and energy security (HMSO, 2003), seeing a shift "away from reducing costs and promoting competition, towards environmental and sustainability goals" (Bolton and Foxon, 2010 p. 16).

If a new, lower carbon generation mix was to be accommodated at least cost, significant innovation in the planning and operation of networks would be required. There was an acknowledgement from Ofgem that whilst the RPI-X price control had been effective in promoting efficiency it was less effective in stimulating research and development or the delivery of new objectives (Shaw et al., 2010; HoCECCC, 2010). Consequently, the fourth price control period saw the introduction of two new mechanisms to encourage network innovation: the Innovation Funding Incentive (IFI) (Section 3.2.1), and Registered Power Zones (RPZ) (Section 3.2.2).

3.2.1. Innovation funding mechanism

The IFI offered support for research and development projects that tackled technical aspects (e.g. network design, operation and maintenance) of distribution networks (up to and including 132 kV) (Sauter and Bauknecht, 2009; Russ, 2005) that had the potential to deliver value to end consumers (i.e. financial, supply quality, environmental, safety). The scheme allowed companies to pass on to customers 80%[1] of their R&D costs up to a maximum of 0.5% of their total revenues (HoCECCC, 2010). A number of network companies, e.g. National Grid, reported using IFI to support work at Technology Readiness Levels (TRLs) between 2 and 8 (National Grid, 2013).

The introduction of the IFI coincided with a significant increase in the level of electricity network R&D investment over the subsequent years (Bolton and Foxon, 2010; Lockwood, 2016; Jamasb and Pollitt, 2015), reversing the steep decline in DNOs R&D investment (Shaw et al., 2010), seeing DNO spending from approximately £1 m in 2003/04 to over £12 m in 2007/08 (Jamasb and Pollitt, 2011, 2015). However, by 2008 network companies had failed to make full use of their 0.5% allowance, spending only £12 m of a potential £20 m R&D, representing only 0.4% of their revenue (HoCECCC, 2010), with some DNOs indicating that the rules governing the areas they could innovate in as too narrow and strict (HoCECCC, 2010). Furthermore, investment post-2008 plateaued up to 2012/13 (Jamasb and Pollitt, 2011, 2015).

3.2.2. Registered power zones

The fourth price control included a DG Connection Incentive, providing DNOs with a means of increasing their revenue through connection of DG projects (Russ, 2005). In parallel, the RPZ scheme supported later stage development and demonstration projects that presented novel and more cost-effective ways of connecting and operating distributed generation (DG) on their distribution systems (Sauter and Bauknecht, 2009). In registering a DG connection as a RPZ the DNO could then receive an additional incentive over and above the main DG incentive (Russ, 2005). A maximum of £500,000 per year during the price control period could be provided to each DNO for RPZ projects, with funding proportional to the level of kW connected (Russ, 2005).

Whilst the scheme encouraged some innovative projects such as the application of active network management in the Orkney Isles to avoid the need for expensive network reinforcement (Currie et al., 2011), the RPZ only delivered four schemes during its five years up to 2010 (Shaw et al., 2010)

3.3. 2008–2015: climate change act and the LCNF

In 2008 GB embarked upon a low-carbon energy transition with the climate change act (HMSO, 2008), carbon budgets (HMSO, 2009a), and a low carbon transition plan (DECC, 2009). Electricity network innovation was identified as a core priority for achieving national decarbonisation targets (LCICG, 2014).

3.3.1. Outline of the LCNF

In 2009 Ofgem proposed the £500 m Low Carbon Networks Fund as a catalyst for innovation within the price control period of 1st April 2010–31st March 2015 (Ofgem, 2009). The stated objective of the LCNF was "to help DNOs understand how they provide security of supply at value for money and facilitate transition to the low carbon economy" (Ofgem, 2010a). Whilst the IFI was also retained, this new

[1] 'Ofgem allowed 90% of the costs of IFI projects to be recovered in the first year of the price control, but this tapered off through the period to 70% in the fifth year, in order to incentivise early take up.' (Lockwood, 2016 p. 118).

mechanism offered much greater sums of funding and allowed for demonstration projects in addition to R&D

The LCNF operated in a tiered format, funding smaller scale projects as Tier 1, and running a Tier 2 annual competitive process to fund a smaller number of large ‘flagship’ projects. Tier 1 projects were allocated a total allowance of £80 million over the 5 years and Tier 2 projects were allocated £320 million (£64 million per year). The remaining £100 million was retained for discretionary awards intended to reward successful delivery of projects. With the IFI still providing a funding route for lower TRL R&D, Tier 1 projects were specifically required to have a TRL between 5 and 8. TRL 9 was excluded, as projects with this TRL were thought to be too low risk and offer limited scope for new knowledge to be generated. A TRL focus was not specifically defined for Tier 2 projects. However, a preference on demonstration was strongly implied with guidance stating projects should not be at the R&D stage and that methods being trialled should be “untested at the scale and circumstance in which the DNO wishes it to be deployed and that consequently new learning will result from the project” (Ofgem, 2010a).

The requirement that learning gained from projects should be disseminated was a key feature of the LCNF. In the guidance for Tier 1 and Tier 2 projects, DNOs were asked to demonstrate that the projects would generate knowledge which did not exist before the proposed trials. Tier 2 bids were also required to show a robust methodology to capture and disseminate the learning (Ofgem, 2010a).

In designing the LCNF, Ofgem sought to simulate the risk and reward that innovation offers to unregulated companies. DNOs were required to provide 10% of the total project cost as a mandatory contribution that could be recovered upon successful delivery. At the application stage, Tier 2 projects were obliged to propose their own Successful Delivery Reward Criteria (SDRC) linked to project milestones, target outputs and learning dissemination activities. The process for award of Tier 2 funding also instituted a direct form of competition between the DNOs.

3.4. 2015–present: post-LCNF

Following a review of regulation for electricity distribution networks, a new framework commenced on 1st April 2015 (Ofgem, 2010b). The RIIO (Revenue = Incentives + Innovation + Outputs) model featured an 8 year price control period and core incentives intended to reward improvements in delivery of services to customers and, in turn, provide an incentive for innovation. In addition, a time-limited innovation stimulus was introduced as a successor to the LCNF. The innovation stimulus includes three measures: a Network Innovation Allowance (NIA); an annual Network Innovation Competition (NIC); and an Innovation Roll-out Mechanism (IRM) (Ofgem, 2013a). NIC and NIA may be seen as analogous to LCNF Tier 2 and Tier 1; however, the scope of NIC is greater than LCNF Tier 2 as it includes development as well as demonstration and allows cross-sectoral work. Both NIC and NIA included an increased focus on customer benefit; however, only the NIC retained a specific requirement for innovation with a focus on low carbon or environmental benefits (Ofgem, 2013a).

3.4.1. Network Innovation Allowance (NIA)

Replacing both IFI and LCNF Tier1, the NIA provides limited funding to RIIO network licensees to “fund smaller technical, commercial, or operational projects directly related to the licensees network that have the potential to deliver financial benefits to the licensee and its customers” (Ofgem, 2017a) and/or help support development of submissions to the NIC. It allows network companies to invest 0.5% of allowed revenues, and in exceptional circumstances up to 1% can be drawn down if they demonstrate a compelling innovation (Ofgem, 2013b). In turn it made available approximately £61 m of funding per annum for network innovation (Ofgem, 2017b).

3.4.2. Network Innovation Competition (NIC)

In contrast the NIC has been designed to support much larger flagship development and demonstration projects than those supported through the NIA (Ofgem, 2017c). Funding is awarded as part of an annual competition, where gas and electricity network companies compete for funding for research, development and trialling for new technologies, operating and commercial arrangements. Successful applicants must: (1) show how their innovations generate new knowledge that can be shared amongst all network operators, (2) provide value for money to network customers both now and in the future and (3) accelerate the move to a low carbon energy sector and/or deliver environmental benefits (Ofgem, 2017c). Overall the NIC is designed to provide £70 m per annum for electricity networks (2015–2016) and £ 20 m for gas networks (Ofgem, 2017b).

3.4.3. Innovation Roll-out Mechanism (IRM)

The IRM has been designed to facilitate the roll-out of Proven Innovations and allow a licensee to recover funding associated with it. The criteria revolve around delivery of carbon reductions, environmental benefits and long term value for money for customers. It must also lead to cost savings that are greater than the implementation costs (Ofgem, 2013c).

4. Studies examining the effectiveness of the LCNF and opportunities for further research

The effectiveness of the LCNF has received some attention in the literature. Lockwood (2016), examining the LCNF in the context of political change, highlights that the LCNF sought to accelerate DNO innovation activity by radically scaling up available funding and requiring engagement with a range of partners, but points to a lack of evidence of any resulting change in business as usual network operation and investment. A high-level summary of LCNF project technical focus found a strong emphasis on information and communication technology (ICT) for monitoring and visualising distribution network state (Jenkins et al., 2015). Rhodes and Van Diemen (2016) reviewed the LCNF with semi-structured interviews of a limited number of academic, industrial and policy stakeholders. The interviews revealed a perception amongst stakeholders that the LCNF had been successful in stimulating DNO RD&D and incentivising a culture of innovation, but there were concerns regarding the quality and rigour of learning methodology and dissemination, and the scheme's ability to nurture radical and disruptive innovations. Evaluation and synthesis of outputs from LCNF projects was not undertaken.

In prior work by the authors of this paper, a review of the outcomes from LCNF projects undertook detailed synthesis and evaluation of learning outputs (Frame et al., 2016). This review established categories to describe the focus of innovation activity and proposed a method for evaluating project learning with respect to the readiness of trialled innovations to be regarded as ‘business as usual’ options. The focus of the review was to gather, synthesize and disseminate the key learning and recommendations arising from LCNF projects, not assess the effectiveness of the LCNF as a regulatory mechanism. However, the methodology and results of the review have since been developed, with additional results and analysis situated in the wider literature allowing further insight to be drawn on the effectiveness of the LCNF and relevant policy recommendations, as presented in the subsequent sections of this paper.

Ofgem commissioned an independent evaluation of the LCNF (Poyry, 2016). The authors drew on the results and methodology from Frame et al. (2016) but focussed on evaluating the potential financial benefits that could be realised as innovations were adopted as core business. Drawing on DNO surveys, the evaluation estimated current realised benefits to be approximately one third of the total funding cost; however, DNOs indicated a belief that all innovations had potential to be adopted as core business and that potential future net-benefit from the LCNF projects was in the range of 4.5–6.5 times the cost of funding the scheme. Detailed analysis of the quality of learning outputs was not included.

Detailed retrospective analysis of flaws in the LCNF design, and hence wider sectoral lessons on innovation stimulus, were not within the scope of these recent reviews; however, a shared observation was the apparent lack of a high-level strategic approach or coordination with the wider industry, resulting in a lack of clear messages with respect to the innovations investigated under the programme.

4.1. The significance of the LCNF for innovation funding in GB

The literature demonstrates that the LCNF was a step change in available network related RD&D funding. Jamasb and Pollitt (2015) note that, at its point of introduction, the LCNF represented an increase in available RD&D financial support by a factor of 5. As set out in Section 3.2, annual expenditure by DNOs on RD&D dramatically declined following privatisation; however, following the introduction of IFI and RPZ, expenditure recovered to just over £12 million in 2007/8 and fluctuated a little up to 2012/13 at which point spend was at around £13 m (Jamasb and Pollitt, 2015).

Full data on actual DNO RD&D spend during the LCNF period has not been published; however, data for four DNOs (Poyry, 2016) shows annual IFI spend relatively stable between £5 m and £10 m, with LCNF spend increasing total spend by an additional £30 m p.a. between 2010 and 2015.

By 31st March 2015, forty Tier 1 projects and twenty-three Tier 2 projects had been approved (Frame et al., 2016; Rhodes and Van Diemen, 2016). In Fig. 1, the approved Tier 2 funding awards per annum are shown, along with the numbers of projects approved or rejected for funding each year. Over the 5 year period, £213 m in total was awarded to Tier 2 projects, representing 67% of the available Tier 2 funding. During the same period, £29.5 m (37%) of the £80 m available for Tier 1 projects was awarded (Frame et al., 2016).

5. Methodology

This paper builds on previous work by the authors (Frame et al., 2016). Two complementary frameworks developed and implemented in that work are formalised and described in detail here.

The first framework was designed to characterise the number and type of network innovation projects that the LCNF has supported; the second to provide a means of assessing the quality of innovation in terms of the learning achieved.

For all 63 projects approved for funding between April 2010 and March 2015, the bid pro-forma was reviewed and a project register populated with data on the innovations trialled, funding levels, and key stakeholders. Following this, a detailed review was conducted of learning outputs from all funded projects that had closed by 31st December 2015. The review included the close-down report for each project and any other specific learning reports also published. In total, over 100 learning output documents were reviewed.

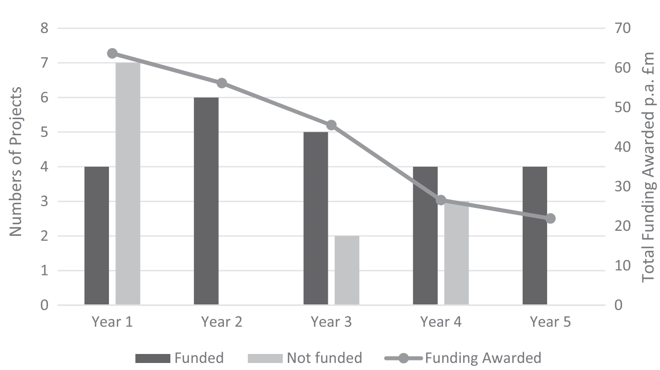

Fig. 1. Numbers of Tier 2 projects and total funding awarded per annum (Frame et al., 2016; Poyry, 2016).

Table 1
Framework for assessing project activity.

High Level Policy Drivers			
Increased Reliability of Supply	Efficient Facilitation of General Demand Growth	Efficient Facilitation of Low Carbon Demand	Efficient Facilitation of DG
Characteristics of DNO's Activities			
Network Visibility and Design		Network Operation	
Improved understanding of system state and limits	Monitoring and Measurement	Power Flow Management	Voltage Control

5.1. Framework for assessing project activity

The framework for assessing project activity is shown in Table 1. It has been designed to capture the high level policy drivers motivating an LCNF project and also the key characteristics of distribution network management around which investigations have centred and learning has been achieved.

5.1.1. High level project drivers

Under the RPI-X regime (Section 3.2), the primary DNO business driver was to provide a network service that met customer demand with sufficient reliability at minimum cost, as set out in the Distribution Code (The Distribution Code Review Group, 2017). Ofgem's LCNF guidance introduced an additional objective: facilitate the low carbon economy. This aligned the role of networks with the energy trilemma: affordability, security of supply and low carbon. The Smart Grid Forum, established by Ofgem and the UK Government's Department of Energy and Climate Change (DECC), comprises a broad range of industry stakeholders and has provided much of the analysis influencing Ofgem's understanding of challenges for electricity networks during the low carbon transition. Drawing on these sources, we define the following set of high level policy drivers:

- Improvement of Reliability of Supply;
- Efficient Facilitation of General Demand Growth;
- Facilitate new Low Carbon Demand; and
- Facilitate Distributed Generation.

5.1.2. Characteristics of Distribution Network Operators' activities

Historically, the role of DNOs has been to manage network assets that allow the transfer of electricity from the transmission network to end customers. The core activities of distribution network planning and design are: load forecasting, substation location and sizing, and feeder routing and sizing (Lakervi and Holmes, 2003). Asset sizing is dictated by accommodating peak power flows within safe thermal limits, and ensuring voltage quality meets statutorily defined standards. Reliability is addressed by including some redundancy in the infrastructure. Cost efficiency is pursued by deploying the minimum amount of 'primary' infrastructure and 'secondary' monitoring and control to achieve these aims safely. However, to date, this has largely been through passive operation whereby operational actions concern responses to faults, repairing affected equipment and restoring supply (Bell et al., 2017).

Prior to the innovation incentives, the Interruptions Incentive Scheme had already driven some innovation by DNOs in respect of operation. This exposed DNOs to financial rewards or penalties in respect of customer interruptions customer minutes lost relative to set targets (Ofgem, 2001). The main outcome was the installation of remote control or, in some cases, automation to reconfigure the network and accelerate the restoration of demand after an outage (Baker and Meisinger, 2011). In addition, the low carbon transition has challenged the passive nature of distribution networks (Bell and Hawker, 2015). New DG and electrification of heat and transport give rise to potentially much higher, more variable power flows. Analysis suggests significant network infrastructure investment would be required to facilitate this using current approaches to network operation. In order to minimise the additional infrastructure required and more effectively utilise it, 'smart grid visions' (European Commission, 2007; ENSG, 2009, 2010) identify a shift from passive network management to more active operation with a focus on the coordinated control of numerous resources across distribution networks, exploiting flexibility in the net flows into or out of the network at different locations – the temporary curtailment of generator output, the utilisation of storage or the time shifting of demand – in order to stay within network limits.

Drawing on a GB focussed framework (ENSG, 2010) and the authors' detailed experience of DNO core business, we define two key functional areas of DNO activity with respect to the challenges introduced by the low carbon transition:

- Network visibility via monitoring and measurement and improved understanding of the system's state; and
- Network operation via power flow management and voltage control utilising the improved understanding of the system's state.

Using this framework, innovations can be mapped to a functional area and then categorised and grouped according to the methods or equipment used.

5.2. Framework for assessing innovation project learning

Based on the importance of knowledge as an output of RD&D and the focus that Ofgem placed on knowledge and learning in the LCNF guidance, we argue here that the success of an innovation project, once funded, should be judged on the quality of evidence generated. The evidence may actually indicate the rejection of the innovation, or the need for further work; if the evidence is strong and clear, the project can be judged to have been a success regardless of whether the innovation is taken further or not. For mature innovations, the evidence should allow robust decisions to be made regarding the commercial viability and cost-effectiveness of the innovation and the conditions under which its deployment is justified. Similarly, projects that provide robust, credible evidence that a less mature innovation remains promising and requires further work, or should be dropped, should also be regarded as successes.

A novel framework for assessing innovation project learning (Table 2), has been developed and implemented as a tool for assessing whether a project has generated robust evidence on how attractive an innovation is for adoption as a core business option ready to be deployed when required.

The framework has been applied to the systematic retrospective review of learning output publications with expert judgement used to interpret both the DNOs' published claims about the innovations and, to the extent that the evidence has been published, the evidence itself. This has been used to evaluate 'Innovation Adoption Readiness' with scoring as shown in Table 2. The highest quality learning outputs are those judged to provide strong evidence and hence allocated scores of +/− 3 or 4.

The scoring criteria are based on an innovation's apparent readiness to cost-effectively address an energy network related need, if and when required. They do not account for the likelihood of the need arising or when it might arise. Part of the point of the innovation funding has been to ensure readiness to accommodate changes to generation and demand arising from the low carbon transition, the precise timing of which is uncertain; if new, cost-effective means of accommodating them have not yet been developed and demonstrated by the time of need, established, less cost-effective or less flexible methods or equipment would have to be used.

A score of + 1 or + 2 suggests a requirement for further development work on the proposed innovation. However, if the need for the innovation is yet to arise, there may be time for that further development work to be carried out. If the various trials have suggested no better solution to the particular system problem at hand and there is confidence that need will arise at some point, investment in further work on such innovations attracting such a score would seem to be justified.

As previously noted, project results have been reported by DNOs in a range of formats with varying quality and depth. We discuss in Section 8 how these limitations could be mitigated and the novel framework and approach described here could be applied within future innovation funding mechanisms.

Given the nature of the LCNF Tier 1 and Tier 2 funding, in many cases a DNO has undertaken one or more Tier 1 projects that laid the foundations for a Tier 2 project. The learning outputs of these projects are limited but complementary to the final Tier 2 project outputs. For these reasons, projects that are linked in this way have been assessed together as one body of evidence, treated, in effect, as a single DNO project with a single Innovation Adoption Readiness.

6. Results

6.1. The objectives of LCNF innovation projects

This section presents a review of the prevalence of projects addressing the different high level drivers and DNO activities outlined in Section 5.1.

6.1.1. High level project drivers

Fig. 2 details the numbers of projects that addressed each high level driver. Each project may have addressed more than one driver. The dominant driver is the facilitation of DG connection to distribution networks. Traditional DNO priorities of facilitating general demand growth and improving reliability of supply receive similar amounts of attention and facilitation of low carbon demand, such as newly electrified heat or electric vehicle charging, is the least prevalent driver.

6.1.2. Characteristics of Distribution Network Operators' activities

The categories identified with respect to Network Operation via Power Flow Management and Voltage Control were:

- Storage;
- Flexible Demand;
- Generator Control;
- Network Reconfiguration; or
- Equipment for Active Regulation of Voltage.

Project activity in these categories is shown below in Fig. 3. Individual projects may have been active in several categories.

Common definitions of smart grid functionality describe the evolution of control functionality at the distribution network layer as a critical aspect of future low carbon networks, e.g. ENSG, 2009; European Commission, 2007. Therefore, during the categorisation process, the method of control was used to further differentiate between innovations. Local Control describes control of a single resource with automated decision making based on measurement of the state of a small number of network assets (often a single specific asset of concern) and a given, local control target or goal. Coordinated Control describes the use of multiple resources and optimisation of the network's state over a wide network area taking fuller account of the

Table 2
Framework for assessing innovation adoption readiness.

Innovation Adoption Readiness		Scoring Criteria
Strong Evidence For Adoption	4	The learning provides a strong conclusion that the innovation is technically and commercially ready for deployment when required and the benefits clearly justify the costs. Few barriers to adoption into core business are noted.
	3	The learning concludes that the solution is technically and commercially ready for deployment when required and benefits clearly justify the costs. However, some further work is required on developing deployment capability and integrating the innovation into existing systems and processes.
Indications For Adoption	2	The learning indicates a good level of benefit relative to expected costs; however, some uncertainty remains around the benefits and costs, some work is still to be done to make the innovation ready for deployment if and when required.
	1	The learning indicates the potential for a reasonable level of benefit which, insofar as the learning includes a cost-benefit analysis, are expected to exceed costs; however, major uncertainty still exists around the potential benefits and expected costs.
Inconclusive	0	The learning fails to provide clear evidence and reaches no clear conclusions on the innovation. However, the work conducted may provide some lessons for further research requirements to provide suitable evidence.
Indications Against Adoption	−1	The learning indicates some possible benefits though, insofar as the learning includes a cost-benefit analysis, costs seem to outweigh the benefits; major uncertainty still exists around the potential benefits and expected costs.
	−2	The learning indicates that the costs of the innovation are excessive relative to the benefit; however, some uncertainty remains around the benefits and costs.
Strong Evidence Against Adoption	−3	The learning concludes that the costs of the innovation are excessive relative to the benefit. It does not explicitly rule out revisiting the trialled innovation or notes that future technical or commercial developments may justify the innovation to be re-examined.
	−4	The learning provides strong conclusions that the innovation is ineffective or the costs are excessive relative to the benefit. It explicitly states no intention to revisit the trialled innovation.

interconnectedness of sites. The numbers of projects using local or co-ordinated control are shown below in Fig. 4. With 51 out of 59 projects, Local Control is clearly dominant.

The categories identified with respect to Network Visibility and Design were:

- *Real Time Thermal Ratings* – the actual power transfer capacity of network assets as influenced by observed, prevailing environmental conditions rather than conservatively assumed conditions;
- *Enhanced Network Visualisation* – utilising network information for planning and operation;
- *Improved Understanding of Existing Demand* – utilising information on existing customer behaviour and consumption to improve knowledge of how demand side customers are using the network;
- *Improved Understanding of low carbon technology (LCT)* – as above, utilising information on customer behaviour and consumption to improve knowledge of potential demand from electrification of transport and new electrification of heat; or
- *Enhanced Network Monitoring* – ICT to gather a range of information on the state of network assets, e.g. the power flow or the voltage.

Fig. 5 details the number of projects addressing each of the Network Visibility and Design categories. Individual projects may have been active in several categories.

Enhanced Network Monitoring is clearly the dominant area of innovation activity across the full project portfolio. Localised Power Flow Management using Storage, Flexible Demand, and Generator Control; and localised Voltage Control using Equipment for Active Regulation of Voltage are the most prevalent innovations related to network operation.

In summary, the main focus of innovation activity has been in improving understanding of network conditions and deploying localised responses to power flow and voltage related network challenges.

6.1.3. Project partners

The stakeholders listed as active partners within each LCNF project are shown in Fig. 6. DNOs have primarily turned to universities and large power systems equipment specialists or consultancies as their main collaborators. The role of local government and local community group partners has been limited. Of the 30 projects involving universities, 22 published key findings on the future benefit of the tested innovation that were based primarily on academic modelling.

6.2. Assessment of innovation project learning

An assessment of the learning outputs was made using the framework described in Section 5.2 for each DNO undertaking projects as part of the LCNF.

6.2.1. Network operation

The Innovation Adoption Readiness scores for network operation innovation projects are plotted in Fig. 7 below.

The distribution of scores, with a concentration in the range − 1 to 1, indicates that a significant number of network operation focussed projects were unable to deliver strong evidence for or against innovation adoption. In particular, storage projects failed to deliver strong conclusions. In contrast, projects on generator control provide strong evidence either for or against adoption in the core business. Examining the detailed scoring for Flexible Demand provides a further example where the evidence is highly mixed. The scoring for the variants of Flexible Demand innovations tested is shown in Fig. 8 where the location and width of the central block indicates the mean and number of projects scored respectively, and the ends of the whiskers indicate the minimum and maximum scores from among the projects addressing

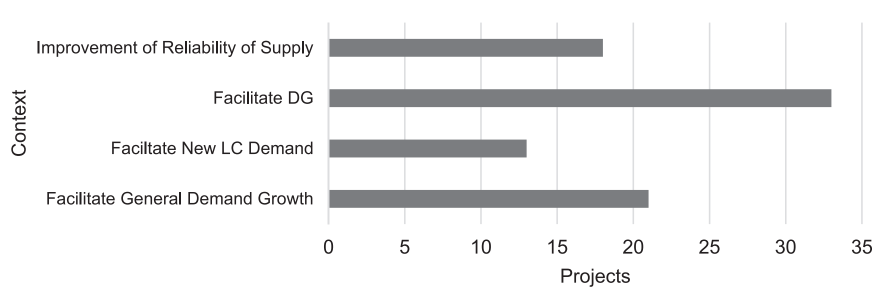

Fig. 2. Number of projects that address each context category.

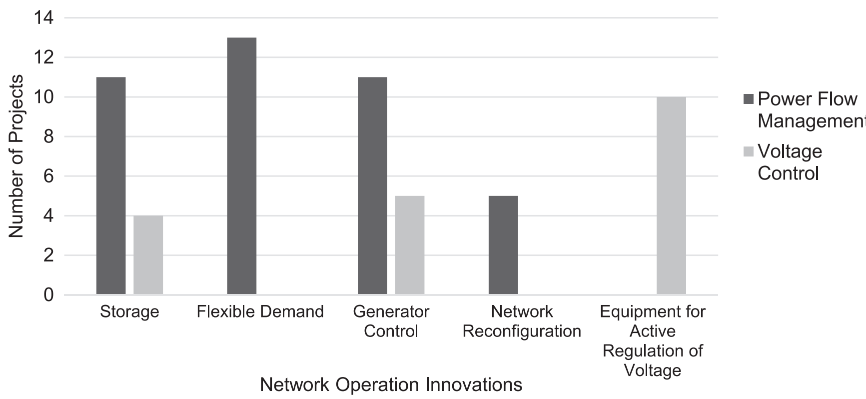

Fig. 3. Project activity in network operation innovations.

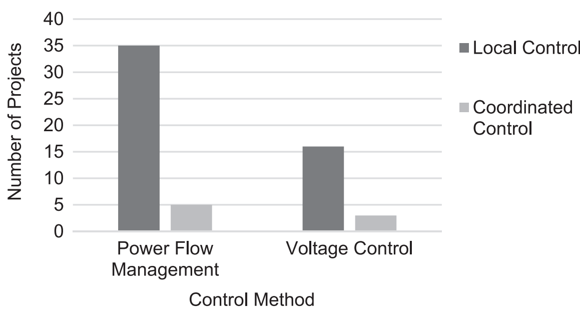

Fig. 4. Projects employing local or coordinated control.

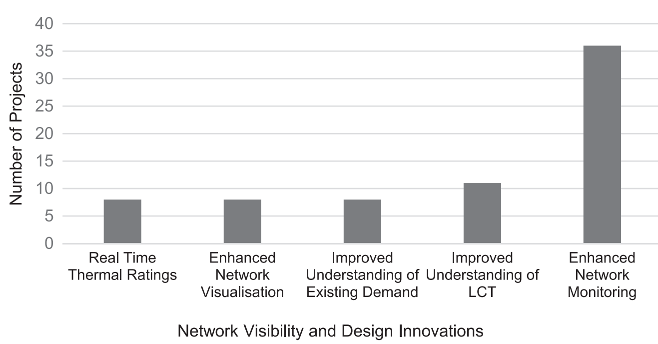

Fig. 5. Project activity in network visibility and design innovations.

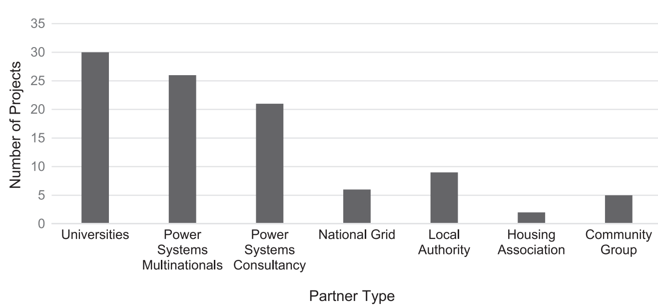

Fig. 6. Number and type of project stakeholders.

that category of innovation.

Methods that involve DNOs operating network assets in a particular way to change the demand for power (voltage optimisation) or contracting with Industrial & Commercial customers provided strong evidence for adoption as core business options. The evidence is less conclusive for innovations more aligned with smart grid visions of control of highly distributed energy resources (DER), such as demand side management or response from residential loads, smart appliances or new low carbon loads such as electric vehicles and heat pumps.

6.2.2. *Network visibility*

The Innovation Adoption Readiness scores for Network Visibility innovation projects are shown in Fig. 9 below. The majority of network visibility projects are concerned with enhanced network monitoring and updating understanding of demand patterns in respect both of individual locations and how demands vary in time. The projects present strong evidence that these innovations should be adopted within core business. Although these results indicate that DNOs have identified value in obtaining data, data itself has no value unless used to provide understanding and knowledge. Innovations focussing on data utilisation appear to be less ready for adoption.

7. Discussion

The review of LCNF background, motivation and structure (Sections 2 and 3) shows the introduction of the LCNF was a direct response to significant shifts in the focus of GB energy policy. With a low carbon transition expected to significantly disrupt the requirements placed on electricity distribution networks, increased DNO RD&D was deemed necessary for networks to evolve appropriately. Comparison of the LCNF against historical RD&D spend demonstrates a step change in the level of funding available for DNO led innovation projects. DNOs, starting from a relatively low level of innovation spend, were expected to rapidly accelerate their innovation activity and deliver large scale projects with a focus on high TRL demonstration. The response of the DNOs to this challenge is explored in this section and findings from the analysis in Section 6 are discussed with respect to the research questions set out in Section 1.

7.1. *Level of innovation support delivered*

The total approved Tier 2 budget over the LCNF period represents a take-up rate of 69% of the available funding, whilst the take-up rate for Tier 1 projects was even less at 37%. In year 1, the full £64 m available for Tier 2 projects was awarded; by year 5 this had reduced to £22 m. A range of factors may be responsible for this underspent funding. The first is that, considering the lack of RD&D funding for network innovation prior to 2008 and that IFI funding restricted internal spend to 15% of project costs until mid-way through DPCR4, the DNOs are unlikely to have possessed sufficient capacity to perform the RD&D being supported by the scheme, particularly in undertaking multiple smaller, in-house, more exploratory innovation projects. This may have manifested itself as a lack of original ideas for network related innovations amongst DNOs even though there can be value in undertaking projects that address similar issues. As Ofgem's guidance says, “Projects that address the same problem, but use a different solution, will not be considered as unnecessary duplicates. Projects that are at different TRLs

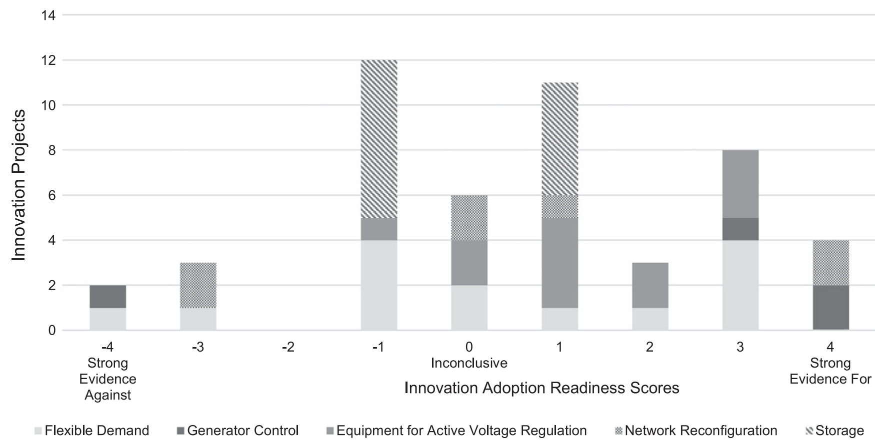

Fig. 7. Innovation adoption readiness scores for network operations focussed projects.

will not be considered as unnecessary duplicates" (Ofgem, 2010a). However, Poyry (2016) found that a number of projects in Year 1 were not funded due to duplication of ideas from which it may be concluded that, in Year 1, DNOs were bidding for similar solutions and/or projects at similar TRLs, arguably reflecting a relative lack of depth and breadth in RD&D thinking.

The second potential reason may also be an indication of a mismatch between the innovation stages, or TRL, the fund was targeting and the maturity of technology at the time. The LCNF guidance for Tier 2 projects indicated pre-commercial demonstration. However, the large degree of university support and associated degree of academic, lower-TRL, work within Tier 2 projects suggests that most innovations of interest to the DNOs were not ready for demonstration and still required significant development before reaching the mid-to-late stage TRLs.

In the context of DNOs' lack of RD&D capacity and the relative lack of demonstration stage projects of interest to DNOs, there is evidence to support an argument that the LCNF design should have been shaped towards encouraging a larger number of smaller, lower TRL projects in the initial years with available budgets starting off small and growing as confidence was gained in DNOs' ability to specify, commission and deliver RD&D. Here RD&D priorities and areas of key uncertainty could be identified, with an increasing focus on demonstration as the fund progressed.

7.2. Type of innovation project activity

The dominant LCNF project driver has been shown to be 'facilitating DG connection'. The resultant project activity has primarily focussed firstly on understanding how best to monitor networks and, secondly, on implementing localised power flow management to maximise the utilisation of existing network assets and, where possible, avoid or defer costly network reinforcement. This was achieved via flexible demand, storage and generator control. Analysis of the type of project activity presents a picture of conservative, incremental innovation. In particular, the several projects focussing on generator control undertook demonstration of reasonably well established active network management technology. This complements the literature's reporting of stakeholder perceptions (Section 4).

Various published innovation agendas, building on the smart grid theme (DECC, 2014; ENSG, 2009; European Commission, 2007; LCICG, 2014), offer ambitious visions with a much stronger importance placed on the implementation of coordinated control of resources across the network, particularly the use of distributed storage and aggregated flexible demand from residential and LCT loads to maximise the utilisation of some given network infrastructure both locally and system-wide. Although DNOs have attempted a significant amount of storage and flexible demand innovation within the LCNF, many projects have mainly focused on single instance trials of equipment that can be deployed, as and when required, in isolation with local control. These were intended to provide a means of deferring conventional investment in additional, local network capacity through additional primary assets such as transformers or cables. Some projects have experimented with wide-area, coordinated control on networks but have not reported clear findings.

Few of the LCNF projects addressed the potential for distribution connected resources to help manage the wider electricity system in respect, for example, of whole system balancing. In many cases, it may be that coordination of multiple instances of novel equipment could realistically only be assessed once some degree of confidence has been gained in the equipment itself and that single instance deployment may offer more immediate rewards with less risk. However, evidence of a strategic approach towards increased coordination was lacking and our

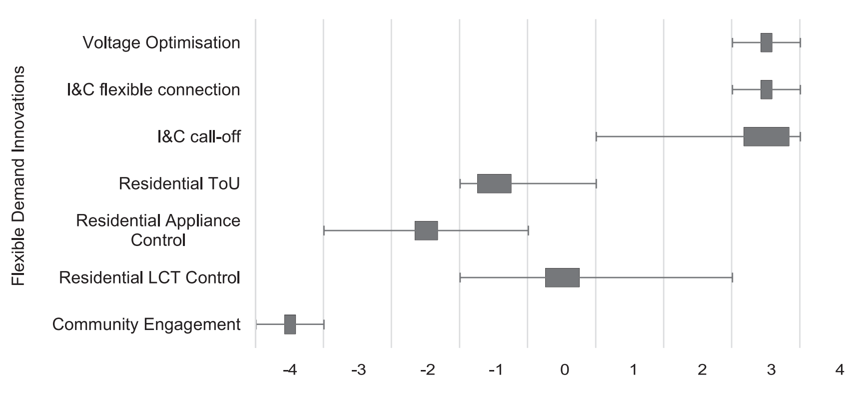

Fig. 8. Innovation adoption readiness scores for flexible demand innovations.

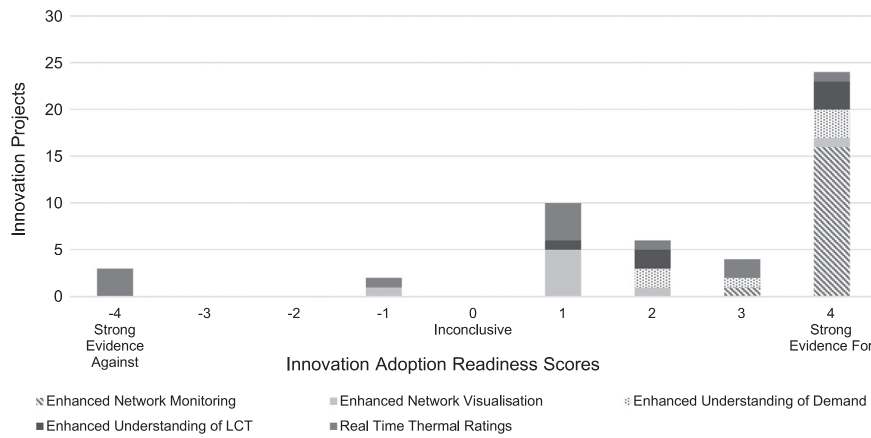

Fig. 9. Innovation adoption readiness scores for network visibility projects.

own experience of distribution networks suggests that there were opportunities for learning in respect of more optimal utilisation of existing equipment and around commercial frameworks that were under-explored in the LCNF projects As the low carbon transition progresses, failure to adopt more coordinated, active approaches to system operation risks either placing unnecessary barriers to the development of low carbon technology or under-utilisation of network assets (Bell and Gill, 2018).

There has been relatively little attention to novel methods, working practices or commercial arrangements, with DNOs' focus in LCNF projects mainly on equipment that was new to them. The attention given to TRLs as an indicator of the maturity of a proposed innovation or the degree of uncertainty associated with it may have, at least indirectly, influenced the focus on technology. (Inevitably, a definition of TRLs will address only technology and not methods or working practices (HoCSTC, 2011)).

7.3. Quality of evidence for innovation adoption readiness

The existence of uncertainty and the imperative to reduce it provides the fundamental justification for allowing the use of customers' money to support network innovation. The aim of innovation funding support should be to reduce uncertainty through the generation of knowledge to the long-term benefit of users of the electricity system. However, in this section we highlight that robust evidence regarding the innovations explored has sometimes been lacking and discuss the possible reasons for this.

In a number of cases there appears to have been poor initial design of experiments where there was a failure to clearly state what information is sought and to define robust methods to obtain it. This may be due to DNOs' inexperience with the specification, management and execution of RD&D projects. Of 63 projects reviewed, 30 had a university as a delivery partner; a key aspect of a university's contribution should be expertise on the framing, testing and reporting of research, but it appears this may not have always been utilised effectively.

The analysis of project learning (Section 6.2) shows that, for several innovation areas, projects produced either contradictory evidence (opposite conclusions on potential for innovation adoption in core business) or were unanimously inconclusive. This observation is based on the evidence as presented and our interpretation of it. A detailed comparison of the trial context or method to explore reasons behind the differing conclusions has not been conducted. Nonetheless, our review highlights a failure of the set of trials addressing an apparently similar innovation to deliver clear messages to the sector and inform either the readiness of the innovation for adoption or the need for further development and evaluation work. Further work by the DNOs involved to compare trial results, explain differences in conclusions and recommend next steps is needed. Comparing this result with the literature reviewed in Section 4, DNO perceptions of potential benefit from innovations, as reported from survey responses, appears significantly more positive than the evidence they report in project learning outcomes.

Although some guidance on potential technology areas and network challenges was provided to DNOs (Ofgem, 2010a), a strategic approach to addressing uncertainty was not established for the LCNF. The lack of a framework for collaborative RD&D with clear guidance and methodologies for knowledge capture and sharing may be a contributory factor to the LCNF's failure to consistently produce strong, clear evidence regarding an innovations potential for core business. It is notable that in March 2017 Ofgem issued a policy decision requiring DNOs to develop a joint innovation strategy that should include aspects such as: identification of key challenges and uncertainties, gap analysis, and coordination and collaboration across the sector (Ofgem, 2017d).

Although the successful delivery reward criteria (SDRC) for LCNF projects included delivery of learning dissemination (Ofgem, 2010a), the requirement was explicitly for delivery of the promised elements of the project, e.g. of a demonstration. DNOs' reporting of the 'success' of a project was usually based on achieving the SDRC, not in terms of how well the learning contributed to existing knowledge, identified and addressed uncertainty, and contributed to the key strategic challenges facing the sector. As a consequence, it is likely that learning on equipment or methods that proved not be effective was under-reported.

The analysis of learning output quality presented in this paper suggests that the process for assessing LCNF project success failed to place enough emphasis on what evidence was sought and the quality of what was obtained. It should also be noted that projects concerned innovations that might be adopted by DNOs and, as a consequence, the DNOs have tended to report the potential benefits in respect of their own current responsibilities, e.g. development and maintenance of distribution network capacity. However, the potential benefits of storage and flexible demand extend beyond the confines of a DNO and represent potentially valuable ancillary services to the transmission system's operator (Bell et al., 2017).

8. Policy recommendations

The following policy recommendations are drawn from the results of this study. They are set out within the context of UK electricity network innovation funding mechanisms, but can be applied more broadly to policy supporting energy technology innovation.

8.1. Setting a clear learning agenda

A strategic approach to learning should be a core part of the design of energy network innovation funding mechanisms with an agreed agenda around the top priorities for sectoral innovation and the type of work that needs to be done to reach joint goals. This should clearly acknowledge that innovation of long-term benefit to energy users can concern not only technology but also methods, working practices and commercial or regulatory arrangements and should be supported by a new set of definitions of innovation maturity and commercial viability that is not limited to technology. The current state of knowledge should be set out with a clear articulation of the critical uncertainties. Alignment with other relevant national and international innovation agendas should be explicit.

8.2. A focus on capacity building

The starting baseline of network licensee RD&D capacity should be well understood and should inform the expected scale of activity during different time periods of the funding mechanism. This should also include the capacity to engage widely with relevant stakeholders in the sector. For example, the analysis of the LCNF engagement in Section 6.1.3 demonstrates widespread engagement with academic partners, but less so with local actors whose priorities may be driving specific changes in electricity network use. The extent of university and consultancy firm involvement provides a positive indicator of DNO willingness to collaborate with wider stakeholders and offers further evidence that the LCNF stimulated DNO RD&D activity that reached across the sector; however, it also provides an indication of a requirement for support, associated with a lack of innovation capacity. By understanding the capacity baseline, along with the critical uncertainties and the sectoral learning priorities, funding priorities can be developed. For example, establishing where a focus on demonstration of a relatively mature innovation is appropriate or where the focus should be on building capacity and accelerating the development of an immature innovation.

8.3. Evaluating project success

Successful delivery criteria linked to a recoverable funding contribution, as demonstrated by the LCNF, may be an appropriate method of incentivising performance in learning outputs in regulated industries; however, reward criteria must be focussed on the quality of learning outputs not just their delivery. A framework for shaping, capturing and assessing the learning outputs of the funded innovation projects is essential.

The framework should support both assessment of projects at the bid stage and ongoing evaluation of success, and should be oriented towards the following: are projects targeting key uncertainties with an appropriate set of planned experiments and, once funded, are they producing high quality learning that moves the knowledge of the sector forward? And, if core business deployment is not yet fully proven, can the knowledge generated and shared be easily built on by a subsequent innovation projects?

In concert with an industry innovation strategy, the framework proposed in Section 4 for evaluating innovation adoption readiness could provide a useful component of ongoing formal evaluation of the 'success' of innovation projects. It could be enhanced to allow formal self-assessment of an innovation's readiness as an option ready to be deployed when required and the required progression in respect of reduction of uncertainty and increase in maturity and commercial viability, accompanied by an in-depth discussion of the supporting evidence produced by the project. For projects with a positive score, a description of the expected pathway towards deployment should be provided. This 'innovation adoption readiness pathway' could then be subject to independent expert scrutiny and would support ongoing knowledge capture, strategy development, and appropriate design of future innovation projects.

9. Conclusions

This paper has assessed the outputs and effectiveness of the UK's flagship £500 m Low Carbon Networks Fund in a bid to inform future policy making on energy network innovation funding. The research finds that the LCNF has facilitated wide-scale knowledge generation. Compared with the situation before LCNF and its smaller scale predecessor, the Innovation Funding Incentive (IFI), the DNOs in Great Britain are considerably more active in RD&D since the LCNFs introduction, collaborating extensively within the sector, particularly with academic partners. This suggests that without the LCNF 'business as usual' would have remained unchallenged and DNOs would not have sought to innovate their core business in a bid to accelerate a low-carbon transition. Consequently, the LCNF represents a leading example of a regulatory policy that has encouraged a step-change of innovation activity across the electricity network industry.

Even so, the study finds that whilst the level of RD&D has increased dramatically, activity could have been even greater as the full funding allocation was not utilised. The attention given to TRLs as an indicator of the maturity of a proposed innovation or the degree of uncertainty associated with it is likely to have led to a focus on technology. There has been relatively little attention to novel methods, working practices or commercial arrangements. In addition, the majority of innovation delivered has been incremental in nature, more concerned with adding network assets that are new to the DNOs and local control rather than more extensive control to optimise network utilisation. The evidence provided by published learning outputs has been either contradictory or inconclusive for several innovations. For two aspects of common concepts of 'smart grids' – flexible demand and storage – LCNF findings as to the case for adoption as standard options within DNOs' core business are particularly mixed.

It has been argued that use of customers' money or public funds is justified if it reduces uncertainty and generates knowledge that benefits customers in the long term. Key policy recommendations relevant to design support mechanism for energy sector innovation are: the need for a strategic approach to reducing uncertainty; a focus on capacity building; and a framework for evaluating the quality of innovation project learning, similar to that implemented in this study. This paper has focussed on evaluation of published project outputs. Future work to further establish the value of the LCNF, NIC and NIA would be: evaluation of innovation adoption within DNO RIIO business plans and a comparison with analogous schemes in other countries to identify best-practice.

Acknowledgements

This work has been carried out as part of the research programmes of the UK Energy Research Centre (Grant EP/L024756/1, www.ukerc.ac.uk/) and HubNet (Grant EP/N030028/1).

References

Aghion, P., Griffith, R., 2005. Competition and Growth: Reconciling Theory and Evidence. MIT Press, Cambridge MA.

Arthur, B.W., 1994. Self-Reinforcing Mechanisms in Economics, Increasing Returns and Path Dependence in the Economy. The University of Michigan Press, Ann Arbor MI, pp. 111–132.

Baker, J., Meisinger, M., 2011. Experience with a distributed-intelligence, self-healing solution for medium-voltage feeders on the Isle of Wight. In: Proceedings of the 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies, pp. 1–4.

Bell, K., Eyre, N., Hawker, G., Castagneto Gissey, G., Dodds, P., Darby, S., Irvine, J., Paul, G., Watson, J., 2017. A Smart, Flexible Energy System: The UK Energy Research Centre's Response to the Ofgem/BEIS Call for Evidence. UK Energy Research Centre, London.

Bell, K., Gill, S., 2018. Delivering a highly distributed electricity system: technical, regulatory and policy challenges. Energy Policy 113.

Bell, K., Hawker, G., 2015. Developing Networks for the Low Carbon Energy Future. UK Energy Research Centre, London.

Bogaert, H., 2006. Reforming network industries: experiences in Europe and Belgium. The

Lisbon Strategy: A Motor for Market Reforms of the Network Industries. Brussels.
Bolton, R., Foxon, T.J., 2010. Governing infrastructure networks for a low carbon economy: the case of the smart grid. In: The UK Third Annual Conference of the Competition and Regulation in Network Industries Journal. Brussels.
Committee on Climate Change, 2016. Meeting Carbon Budgets – 2016 Progress Report to Parliament. London.
Currie, R., MacLeman, D., McLorn, G., Sims, R., 2011. Operating the Orkney smart grid: practical experience. In: The 21st International Conference and Exhibition on Electricity Distribution (CIRED). Frankfurt.
CIGRE, 2010. Planning to manage power interruption events, Working Group C1.17, Technical Brochure 433. CIGRE, Paris.
DECC, 2009. The UK Low Carbon Transition Plan. London.
DECC, 2014. Smart Grid Vision and Routemap. London.
DECC, 2015. Towards a Smart Energy System. London.
Economides, N., 2006. Competition policy in network industries: an introduction. In: Jansen, D.W. (Ed.), The New Economy and Beyond Past, Present and Future. Edward Elgar, U.K.
Elkington, J., 1997. Partnerships from Cannibals with forks: the triple bottom line of 21st century business. Environ. Qual. Manag. 199, 37–51.
ENSG, 2009. Electricity Networks Strategy Group: A Smart Grid Vision. London.
ENSG, 2010. Electricity Networks Strategy Group: A Smart Grid Routemap. London.
European Commission, 2007. Strategic Research Agenda for Europe's Electricity Networks of the Future. Brussels.
European Commission, 2013. Market Functioning in Network Industries – Electronic Communications. Energy and Transport, Brussels.
Frame, D.F., Bell, K., McArthur, S., 2016. A Review and Synthesis of the Outcomes from Low Carbon Networks Fund Projects. UK Energy Research Centre and Supergen HubNet, London.
Grubler, A., Aguayo, F., Gallagher, K., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G., Wilson, C., 2012. Policies for the Energy Technology Innovation System (ETIS), Global Energy Assessment – Toward a Sustainable Future. Cambridge University Press, Cambridge.
Haas, M., 2006. Management of Innovation in Network Industries: The Mobile Internet in Japan and Europe. German University Publishers, Wiesbaden.
Hines, P., Balasubramaniam, K., Sanchez, E.C., 2009. Cascading failures in power grids. IEEE Potentials 28 (5), 24–30.
HoCSTC, 2011. Science and Technology Committee - Second Report of Session 2010–11. Technology and Innovation Centres. London.
HMSO, 1957. Electricity Act. London.
HMSO, 1989. Electricity Act. London.
HMSO, 2000. Utilities Act, Chapter 27. London.
HMSO, 2003. The Sustainable Energy Act. London.
HMSO, 2008. Climate Change Act 2008, c.27. London.
HMSO, 2009a. The Carbon Budgets Order 2009. London.
HMSO, 2009b. National Renewable Energy Action Plan for the United Kingdom. London.
HoCECCC, 2010. Energy and Climate Change Committee – Second Report. The future of Britain's electricity networks. London.
IEA, 2003. World Energy Investment Outlook. International Energy Agency, Paris.
IRENA, 2017. Stranded Assets and Renewables: How the Energy Transition Affects the Value of Energy Reserves, Buildings and Capital Stock. International Renewable Energy Agency (IRENA), Abu Dhabi.
Jamasb, T., Pollitt, M.G., 2011. Electricity sector liberalisation and innovation: an analysis of the UK's patenting activities. Res. Policy 40, 309–324.
Jamasb, T., Pollitt, M.G., 2015. Why and how to subsidise energy R + D: Lessons from the collapse and recovery of electricity innovation in the UK. Energy Policy 83, 197–205.
Jenkins, N., Long, C., Wu, J., 2015. An overview of the smart grid in Great Britain. Engineering 1, 413–421.
Lakervi, E., Holmes, J., 2003. Electricity Distribution Network Design: IET Power Engineering Series 21. London.
Littler, D.J., 1980. Management of research in the central electricity generating board. IEE Proc. A – Phys. Sci. Meas. Instrum., Manag. Educ. – Rev. 127, 625–628.
Lockwood, M., 2016. Creating protective space for innovation in electricity distribution networks in Great Britain: the politics of institutional change. Environ. Innov. Soc. Transit. 18, 111–127.
LCICG, 2014. Coordinating Low Carbon Technology Innovation Support: The LCICG's Strategic Framework. Low Carbon Innovation Co-ordination Group, London.
Mission Innovation, 2016. Mission Innovation: accelerating the clean energy revolution. Available at: http://mission-innovation.net/ [Accessed June 29, 2016].
National Grid, 2013. Innovation Funding Incentive Annual Report 2012/13.
National Grid, 2016. UK Future Energy Scenarios. Warwick, UK.
North, D.C., 1990. Institutions, institutional change, and economic performance. Econ. Perspect. 5, 97–112.
Ofgem, 2001. Information and Incentives Project Incentive Schemes: Final Proposals. Office of Gas and Electricity Markets, London.
Ofgem, 2009. Electricity Distribution Price Control Review Final Proposals. Office of Gas and Electricity Markets, London.
Ofgem, 2010a. LCN Fund Governance Document v.1. Office of Gas and Electricity Markets, London.
Ofgem, 2010b. Regulating Energy Networks for the Future: RPI-X@20 Recommendations. Office of Gas and Electricity Markets, London.
Ofgem, 2013a. Electricity Network Innovation Competition Governance Document. Office of Gas and Electricity Markets, London.
Ofgem, 2013b. Price Controls Explained – Factsheet 11. Office of Gas and Electricity Markets, London.
Ofgem, 2013c. Strategy Decision for the RIIO-ED1 Electricity Distribution Price Control. Office of Gas and Electricity Markets, London.
Ofgem, 2017a. Electricity Network Innovation Allowance Governance Document V.3. Office of Gas and Electricity Markets, London.
Ofgem, 2017b. The Network Innovation Review: Our Policy Decision. Office of Gas and Electricity Markets, London.
Ofgem, 2017c. Electricity Network Innovation Competition Governance Document v.3. Office of Gas and Electricity Markets, London.
Ofgem, 2017d. The Network Innovation Review: Our Policy Decision. Office of Gas and Electricity Markets, London.
Pierson, P., 2000. Increasing returns, path dependence, and the study of politics. Am. Polit. Sci. Rev. 251–267.
Poyry, 2016. An Independent Evaluation of the LCNF – A Report to Ofgem. London.
Rhodes, A., Van Diemen, R., 2016. Has the low carbon network fund been successful at stimulating innovation in the electricity networks? In: British Instutite of Energy Economics 2016: Innovation and Disruption: The Energy Sector in Transition. Oxford.
Russ, N., 2005. Distributed generation – regulating for change. In: Proceedings of the 18th International Conference and Exhibition on Electricity Distribution CIRED. Turin.
Sauter, R., Bauknecht, D., 2009. Distributed generation: transforming the electricity network. In: Scrase, I., MacKerron, G. (Eds.), Energy for the Future: A New Agenda. Palgrave, Basingstoke, UK.
The Distribution Code Review Group, 2017. The Distribution Code of Licensed Distribution Network Operators of Great Britain v28. 〈http://www.dcode.org.uk/assets/uploads/DCode_v28_May_2017_020517_final.pdf〉, (Accessed 19th December 2017).
Shaw, R., Attree, M., Jackson, T., 2010. Developing electricity distribution networks and their regulation to support sustainable energy. Energy Policy 38 (10), 5927–5937.
UKRN, 2015. Innovation in Regulated Infrastructure Sectors. UK Regulators Network, London.
UNFCCC, 2016. The Paris Agreement. Available at: http://unfccc.int/paris_agreement/items/9485.php [Accessed December 19, 2016].