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Policy, niches and diffusion in UK smart grid innovation

Alaa Owaineh, Matthew Leach, Paul Guest and Walter Wehrmeyer

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Introduction

This paper examines the evolution of smart grid innovation in the UK. Starting from the premise that the industry context drives innovation in the first instance, the paper examines key features of smart grid development. The paper looks at the main actors and groups involved in developing smart grids generally, and particularly those responsible for specific innovations. It then goes on to discuss the governance and funding structure supporting smart grid innovation, and the challenges expected for the sector. To demonstrate the development of smart grid innovation, the paper presents the most well-established smart grid demonstration projects in the UK, the Orkney Active Network Management Project.

Energy Industry Context and Drivers

The UK electricity infrastructure will face growing challenges over the coming decades. One factor is the growing electricity demand, partly driven by the expected increase in electrification of transport and heat (G&S KTN, 2011; DECC, 2013). An increasing proportion of generation capacity will be transferred to small-scale generation that will have to be connected to the distribution network (SGF, 2014; DECC, 2013). These changes will increase the pressure on the electricity transmission and distribution networks and on generation capacity (G&S KTN, 2011; DECC, 2013). At the same time, major components of the existing infrastructure, across generation, transmission and distribution, are reaching the end of their lives, and need to be upgraded or replaced, requiring investment amounting to £100bn (€120bn), according to the recent Electricity Market Reform Bill (DECC, 2013).

The electricity industry in the UK has to maintain the electrical supply while trying to balance a number of competing goals. Firstly, they need to deliver a reliable supply, but limit consumer price rises. Secondly, if the UK is to meet its emission reduction obligations, this would entail a very sharp reduction in the carbon intensity of electricity by 2030 (G&S KTN, 2011, the CCC, 2013). The sector has to achieve this despite consumer mistrust and exposure to policy uncertainty (Rosenfield, 2010).

UK smart grids: Visions, actors and expectations

Definitions of the smart grid

The definition of smart grids is still emerging as the technology, users and systems develop but broadly it refers here to a family of inter-related technologies that use a wide range of sensors and data sources to collect information on the operation of the electricity network. This data can be collected automatically at the transmission, distribution or use levels. The information can be used to automate certain actions based on algorithms embedded in the system, such as demand side response. The data can also be used to provide users with information that may prompt them to change their behaviour or allow them to make better decisions. The process of creating a smarter system is often conceived of as an integration of information and communications technology (ICT) into the energy infrastructure (Rosenfield, 2010; Wolsink, 2012).

A number of technologies are perceived as forming the building blocks of smart energy systems. An illustrative list of these include sensing and monitoring technologies at the network or supply side, such as phasor measurement units (PMUs); communication technologies which turn the grid essentially into a communications network, and demand-side technologies such as smart meters and smart appliances. Above this layer, there is a need for advances in coordination and management technologies to use the different components (EG&S KTN, 2011). Another challenge to defining smart grids is that the boundary between them and the related smart homes and smart metering technologies are still not clear.

One explanation of the vague definition of a smart grid is that it is an industry buzzword (Wolsink, 2012). A more likely explanation is that the smart grid, as a concept and as a sociotechnical system, is still at an early stage of its development and therefore its definition can only stabilise as the system matures. The field of Science and Technology Studies (STS) provides many examples of this process in emerging sociotechnical systems (MacKenzie & Wajcman, 1985; Faulkner et al., 2010). This is described by some authors, such as Bijker (1989) as "interpretive flexibility", whereby "relevant social groups" ascribe different meanings to a technology. The definition of a technology only becomes stable as a result of a process of negotiation and "closure". (Bijker, 1989). A different approach to understanding sociotechnical systems, Actor-Network Theory, similarly argues that networks of actors are formations that contain both human actors and technological artefacts, and it is only once the configuration of this network stabilises that the definition of a technology becomes widely agreed (Faulkner et al., 2010). Rather than being a problem, this fluidity in the definition is a research opportunity, insofar as the meanings ascribed to the smart grid by different actors and their interests in it can be examined before they are obscured by a process of closure and standardisation.

Visions of future networks

The expectations from the smart grid are very high, and Ofgem and DECC are clearly counting on it to solve many of the problems facing the energy system. Even though the direct benefits are only expected to accrue from 2020 onwards, action is needed now to support the transition to smarter electricity networks, hence benefiting from the opportunity to go beyond simple maintenance, to innovation, and upgrade the grid to cope with future challenges (SGF, 2014).

Smart grid technologies will have far-reaching impact on utilities' business model and on the relationship between actors. Because of the way they create a more distributed and transactional energy system, and because they allow the system to control energy demand, rather than just generation, these technologies have the potential to completely transform the relationship between utilities, households, and large industrial users and increase the involvement of users in the system (Foxon, 2012; Rosenfield, 2010).

In terms of network architecture, smart energy systems will also represent a radical shift. Historically, the electricity system has been centralized and based on large-scale generation (Pearson and Watson, 2012; Hammond, 2000; Morrison and Lodwick, 1981). The structure of the electricity system has been largely unchanged – large centralized thermal (or occasionally hydroelectric) power stations generate the bulk of the electricity, which is then moved closer to users using high-voltage transmission lines, then transferred to local low-voltage distribution networks. However, smart grids will be much less centralized, with information, control, and power flowing across a bidirectional network. The figures below demonstrate how radical this transition can be. Figure 1 illustrates the current structure of the system, and Figure 2 shows a simplified view of how the system may look like in the future with data and power flowing in both directions, and much more energy storage, and distributed generation.

Figure 1: Current electricity network structure is linear and centralised

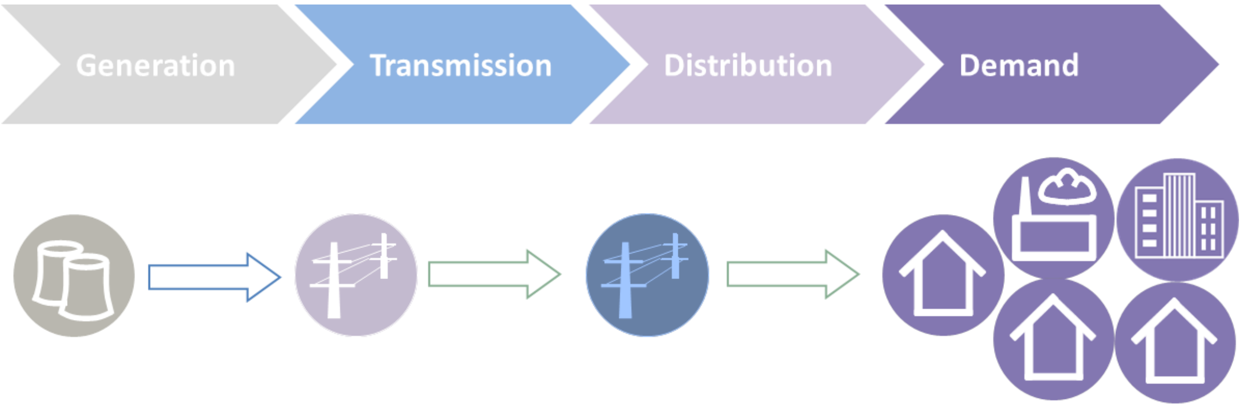
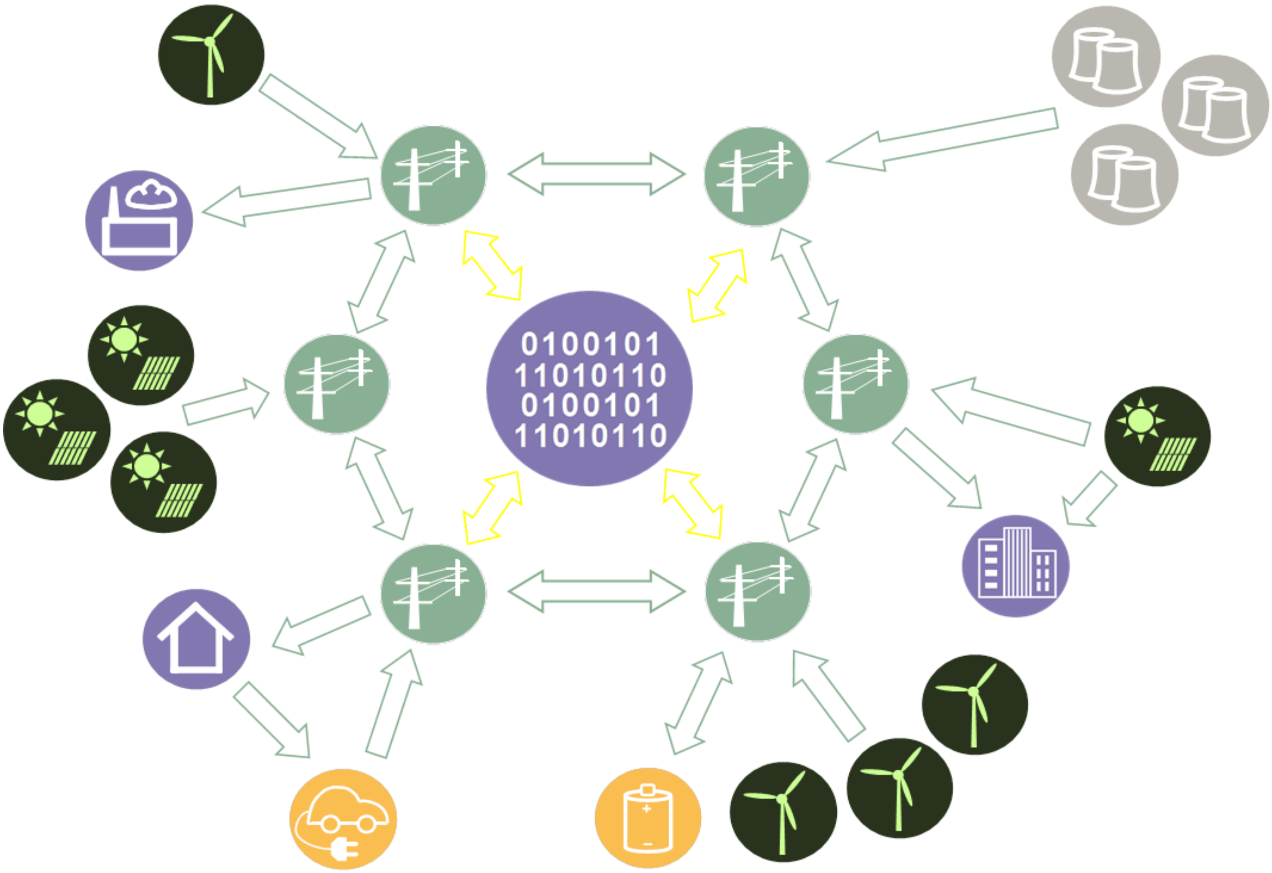


Figure 2: The network is expected to become more decentralised and transactional, and carry data as well as power



Key actors influencing smart grid innovation

Many different actors are involved in the smart energy system, and many more are likely to get involved. Some of these will have a purely technological role, while others will have hybrid roles, or market roles. Parties with an interest in the market include suppliers, distribution network operators (DNOs), transmission network operators (TNOs), consumers, universities, the government, regulators, think-tanks and community groups.

Companies providing and developing the underlying smart grid technology are also important. These range from large infrastructure providers like GE and Siemens, to specialist smart meter manufacturers like Elster and Landys+Gyr, (EG&S KTN, 2011) to small start-ups like Smarter Grid Solutions. The smart grid will also create a space for new types of businesses or organisations, as well as consultancies and smart home technology developers. The integration between ICT and energy systems will mean that IT companies like IBM, and telecommunications providers will also need to get involved in this market. Indeed, there is strong evidence that ICT firms have gained influence on the development of smart grids , and have driven innovation in the sector through variety creation (Erlinghagen and Markard, 2012). Industry associations, such as Smart Grid GB and the Energy Networks Association in the UK, the Gridwise Alliance in the US, and the Global Smart Grid Federation also have in influence through lobbying and research.

In terms of involvement in specific projects, Table 1 below provides examples of specific smart grid demonstrations in the UK and lists the partners directly involved in the project and the degree of their involvement. It illustrates the range of actors who are connected to smart grid innovation niches.

Table 1: Examples of the actors involved in UK smart grid projects

	High involvement	Medium involvement	Low involvement
Orkney ANM	SSEPD University of Strathclyde Smarter Grid Solutions Local renewable generators Community energy groups	Ofgem SSE	Scottish Government USI (Power Donut) DNV Kema Sparx Systems BT
E.On MK2000	E.On Households Greenwave	Appliance manufacturers Smart meter manufacturers	Other suppliers
Smart Hooky	Western Power Distribution Hook Norton Local Authority Local community group Ranesas Electronics AND Tech Research	Ofgem National Energy Foundation Households Local businesses	
Low Carbon London	UK Power Networks National Grid Greater London Authority Imperial College London Siemens Ofgem	Smarter Grid Solutions EnerNOC Flextricity EDF Energy CGI (Logica)	Institute for Sustainability Transport for London

The Orkney Islands Active Network Management project – This project is based on the Orkney Islands in the North of Scotland. It is one of the most advanced and well established in the UK and is interesting in that it was built on previous collaboration between the University of Strathclyde and the local DNO, SSEPD and on the high investment in wind and wave energy on the Orkney Islands. The project and its precursors have all been made possible by various rounds of funding from the energy regulator Ofgem, going back to 2005, including the Registered Power Zone (RPZ) incentive, and the Low Carbon Network Fund (LCNF). The project has resulted in the creation of the spin-off company, Smarter Grid Solutions, which is now involved in implementing the technology that was developed within the project to other smart grid trials in the UK. The Orkney ANM has benefited from significant buy-in from local small-scale generators and community groups who have had a high degree of support and involvement in the project. A more detailed account of this project will be proposed in this paper.

E.On MK2000 – Primarily a smart homes project, it focuses on testing a broad range of technologies initially in a test house leased by the company, and then in one of 75 homes in Milton Keynes, a town about 85 kilometres north west of London. The technologies tested include smart appliances, smart home hubs, Solar PV monitoring systems, smart power plugs, lighting controls, and heating controls. The project started in 2011, and has already collected a significant amount of consumer feedback. Much of the control and management technology being tested is developed by E.On's key partner, a start-up called Greenwave.

Appliance and smart meter manufacturers are also involved in the project and it serves as a testing ground for the integration between smart home, smart metering and smart grid technologies and the impact of that integration on consumers.

Smart Hooky – Based in Hook Norton, a village in Oxfordshire, this project is a collaboration between the local authority and the DNO, Western Power Distribution (WPD). The project is funded by the LCNF and claims to be the first community scale smart electricity grid project in the UK. It involves installing monitoring nodes in 40 households and connecting them to a smart hub at the distribution sub-station. The project is also experimenting with the underlying communications technology, and has used power line communication (PLC) to connect homes to the smart hub, doing away with the need to have a separate dedicated communications infrastructure. Two of the key partner in the project, AND Technology Research, and Ranesas, developed the underlying monitoring components for the project and part of the communications infrastructure. The project is also notable because of the high degree of involvement of local businesses and local community groups, as well as the National Energy Foundation, a charity involved in improving energy efficiency.

Low Carbon London – Yet another LCNF project, which is also led by the local DNO, UK Power Networks. However, the project boasts a broad coalition of partners. These include utilities such as EDF Energy and British Gas, and the transmission operator, National Grid. It also has diverse group of technology providers and developers: aggregators like Enernoc and Flextricity; CGI, a systems integrator; the Greater London Authority; Transport for London; Siemens; Imperial College; The Institute of Sustainability; and Smarter Grid Solutions (the spin-off start-up from the Orkney ANM project). The project involves a number of smart metering and smart grid trials, across domestic and business sectors, as well as electric transport trials.

Many actors have very high expectations from smart grids

The development of smart grids is perceived as being a very important factor in solving the problems facing the sector. For instance, a report published by the Smart Energy Special Interest Group, and authored by the Energy Generation and Supply Knowledge Transfer Network (EG&S KTN) in 2011 unequivocally highlights the “unprecedented scale of external and internal challenges that will affect each segment of the electricity grid supply chain in the near future” and that “addressing these challenges in a cost-effective way requires the redesign of the grid to make it smarter” (EG&S KTN, 2011: 1). Investments in the smart grid in the UK are expected to bring monetary value to the industry, with the potential net benefit in avoided network upgrade costs expected to be between £2.4 and £8.1 billion. This is in addition to other indirect benefits such as gaining technology leadership that can be exported globally, meeting emissions reduction targets, avoiding the need for additional peak generation, and many others (EG&S KTN, 2011).

A range of benefits is expected from the adoption of the smart grid across a range of areas. These include the ability to integrate more renewables and other distributed generation sources (Wolsink, 2012; SGF, 2014; EG&S KTN, 2011), better fault detection and repair, and the ability to implement demand-side response systems to manage peaks (Rosenfield, 2010;EG&S KTN, 2011; the CCC, 2013). The smart grid will provide unprecedented volumes of data on energy usage at the household and, potentially, even appliance level.

While no one is quite sure how these data are going to be used yet, they will allow for new ways of reducing energy consumption and controlling demand (Rosenfield, 2010;EG&S KTN, 2011; the CCC, 2013), as well as creating different services and business models.

A Pike Research report estimates that global spending on smart grid technologies will reach US$200 billion (€145 billion) by 2015. Ofgem estimates that the updating of Britain's ageing transmission and distribution network would require investments in the tune of £32 billion. This represents a doubling of the industry's historical investment over the past 20 years (EG&S KTN, 2011). Such a level of expenditure will create secondary benefits in addition to the primary benefits of adopting smart grids. A number of studies looking into the cost-benefit analysis of the smart grid disagree on the extent of the benefit, but all are very optimistic about the return on investment in smart grid technology (Lockwood, 2013; SGGB, 2012; SGF, 2014).

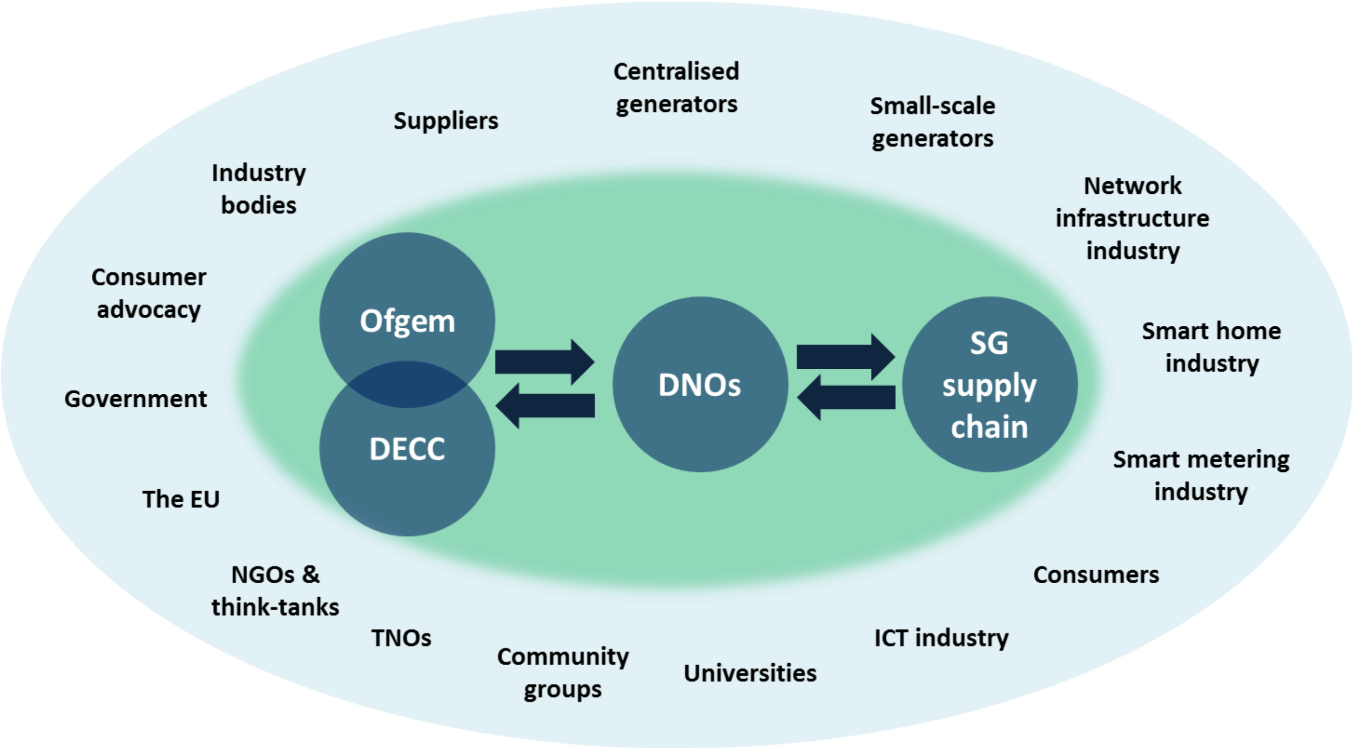
The most widely cited analysis of the economic benefits of smart grids in the UK is a report authored by Ernst & Young on behalf of Smart Grid GB. The report predicts substantial benefits in terms of competitiveness, exports economic value and job creation. It estimates that by 2050 smart grids could cumulatively add £13bn of gross value to the economy and create opportunities for £5bn worth of exports. In addition, the assessment expects the creation of 8,000 new jobs by 2020 and a further thousand by 2030 across the entire supply chain for smart grids and secondary related markets (SGGB, 2012). The expectations are generally very high and extremely optimistic, a sign that smart grids are seen as an important opportunity by many actors.

DNOs, Ofgem and the creation of smart grid innovation spaces

In the UK, much of the activity around smart grid development is at the stage of demonstration projects and pilots, as well as the on-going smart meter roll-out (if that is defined as part of the smart grid). The majority of smart grid development is being led by DNOs, and supported by funding from Ofgem's Low-Carbon Network Fund (LCNF). DNOs own the distribution network and have to carry the biggest risks of stranded assets and bear the high initial costs if they choose to start proactively investing in preparing their infrastructure for a smart grid transition (SGF, 2014). DNOs also need to be ready to scale up smart grid technology quickly and flexibly to deal with the many uncertainties around the rate and magnitude of the uptake of renewable energy technologies and electric vehicles, and other changes in energy usage patterns (SGF, 2014).

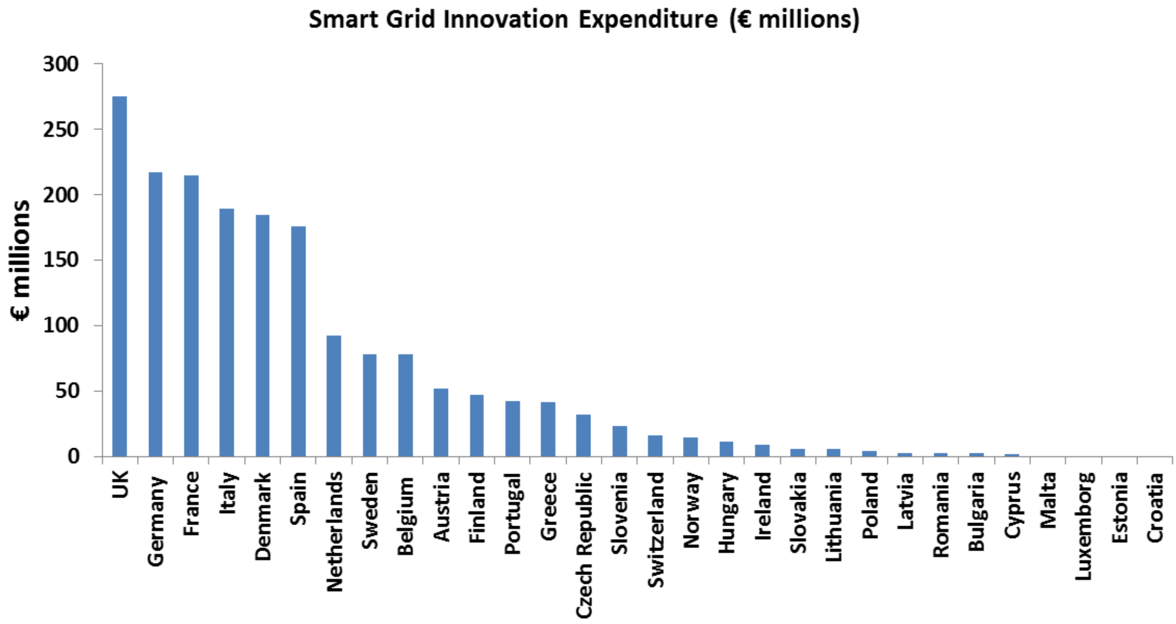
The government, particularly DECC has a great influence through policy and legislation, but this is mostly an indirect influence on specific smart grid projects. Within those niches, it is the energy regulator, Ofgem, that has the more direct influence through the funding and monitoring of specific demonstration projects. This funding operates through specific schemes for innovation, most notably the LCNF, which is one of the biggest sources of funding for smart grid pilots in Europe (JRC, 2012). The funding and drive for innovation that is generated in the interaction between Ofgem and DNOs is the primary nexus of smart grid innovation in the UK. DNOs then act as the main source of technology pull and downstream funding for the development of an innovative supply chain, as well as testing new business models and practices and creating opportunities for learning within those niches. However, these niches of innovation are embedded in a broader regime and are influenced by the actions of many more actors that may not be directly involved in them.

Figure 3: Policy and funding by Ofgem spurs DNOs to create spaces for innovation in smart grid technology



The level of investment in smart grid innovation and the number of demonstration projects put the UK at a potentially favourable position (SGF, 2014; JRC, 2012). Investment in smart grid technology development and demonstration projects is estimated at around £230 million/€275 million by the JRC (2012). LCNF projects account for the majority of this investment. UK investment in smart grids represents around 15% of total European spending on smart grid innovation (R&D and pilots) captured by the JRC's database. The majority of spending in the UK is on pilot projects and larger-scale demonstrations (JRC, 2012; SGF, 2014), which allows actors to test evolving business models, policies, and better understand the skills needed to implement smart grids. This goes beyond purely technological innovation which is often the focus of R&D projects.

Figure 4: Levels of smart grid innovation investment in Europe



Source: Smart Grids Observatory, 2014

This leading position for the UK represents a significant improvement in terms of grid innovation. A regulatory regime can often be a disincentive to grid innovation, and this was the case in the UK, particularly for DNOs and TNOs, whose revenues had historically been strictly governed by the RPI-X formula since the 1980s, when privatization took place. The main aim of RPI-X was to deliver efficiency and operational effectiveness within DNOs in a relatively stable technology and governance structure. This governance structure was appropriate, because the costs of not innovating were small, and because it was delivering substantial efficiency improvements (Smith, 2010). RPI-X did not, however, encourage innovation beyond quite narrow operational improvements (Ofgem, 2010; Smith, 2010). Up to the early 2000s, the policy context for electricity networks in the UK discouraged innovation or change. By 2004, it is estimated that British DNOs were spending only around 0.1% of their revenues on R&D and demonstration projects (Lockwood, 2013). Even with Ofgem's introduction of specific schemes to fund network innovation in 2005, funding for demonstration and research projects still had to be justified in terms of reducing costs to consumers rather than environmentally beneficial outcomes, and there was much more focus on technological innovation rather than system innovation (Lockwood, 2013).

In terms of policies to support smart grid initiatives, Ofgem's LCNF is highlighted as the main one, with £500m worth of funding. The RIIO (Revenue=Incentives+ Innovation +Outputs) price control model that Ofgem is proposing for both gas and electricity markets is also aiming at including support for innovation within the incentive structure for the transmission and distribution networks. Building on the LCNF, a new framework called the "innovation stimulus" will come into effect. This framework supports innovation by funding large scale projects, and providing a network innovation allowance of between 0.5% and 1% of each

DNOs revenues to be allocated to smaller projects. Additionally, the RIIO –ED1 (the RIIO version adapted to electricity distribution) addresses the diffusion of successfully demonstrated low-carbon innovations by having a mechanism to fund their roll-out. Finally, there is a requirement for DNOs to report on how they will learn from innovation trials and demonstrations and carry that knowledge over to their business-as-usual operations (Lockwood, 2013).

Challenges for governing smart grid innovation

The direction for innovation in smart grids in the UK is outlined by SGF (2014) and sees the near term challenges as enabling increased consumer participation, and ensuring consumer buy-in, essential prerequisites for demand response. From a policy perspective, developing an appropriate regulatory and institutional framework, maintaining a clear strategic vision that can allow diverse actors to move in broadly the same direction are seen as the most important. Finally developing the right technology is highlighted as the key technical challenges. The most important of these is likely to be getting the policy right, since that is one the main determinants of consumer participation and accelerated technology development.

Projects supported by LCNF have been successful. But Lockwood (2013) argues that while UK policy has been successful at creating niches for experimentation around smart grid systems it remains unclear how innovations can be diffused more widely. Paying more explicit attention to moving these innovations from the niche level to the wider regime remains an important policy challenge. There has also been some criticism of the tendency among policy makers not to dictate technology choices and try to keep technological options open, as a result he argues that there is a real risk that "keeping options open can translate into inaction unless the outcomes are tightly defined by government and aligned with a rapid transition to a smart grid future" (Skillings, 2010: 7). These issues need to be overcome to take the development of the industry to the next level from niches to wider diffusion.

Another challenge is finding ways of integrating innovations around smart metering, as part of the mandated smart meter roll-out, and those being developed from smart home trials, in the development of the smart grid. Such integration is likely to be important for the smart grid to realise its potential benefits. This is not easy, since smart metering and smart home innovations are being led by suppliers rather than the DNOs (with limited DNO involvement). The 53 million or so smart meters to be installed in the UK will provide unprecedented volumes of data on energy usage at the household and, potentially, even appliance level. (Rosenfield, 2010;EG&S KTN, 2011; the CCC, 2013). It is not clear which actors are best placed to deliver services based on this data and create value from it. Another source of uncertainty is consumer attitudes towards allowing access to this data.

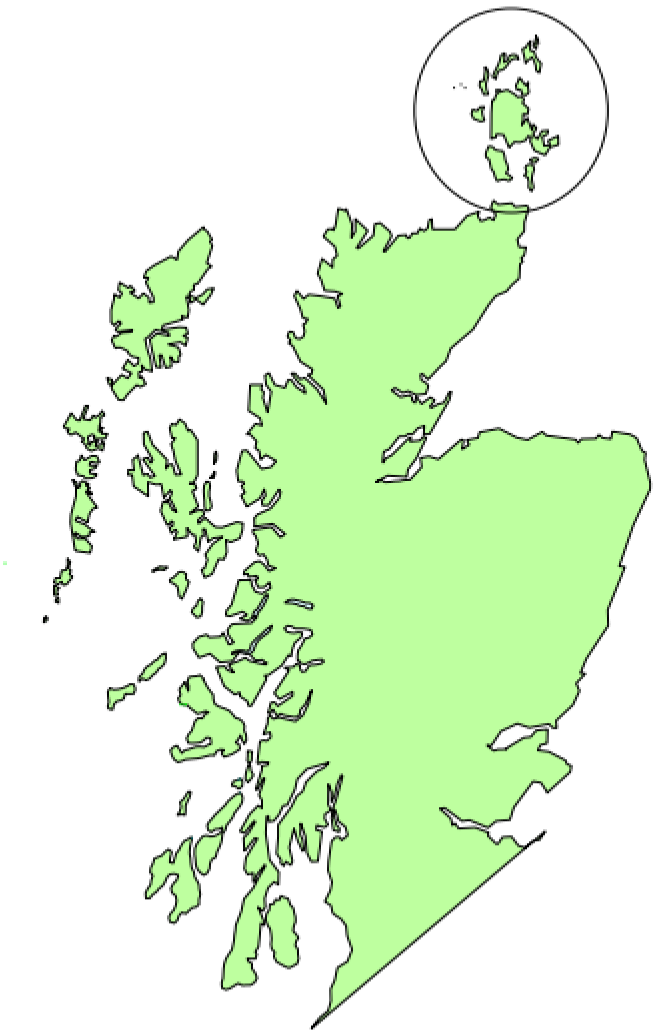
Case Study: The Orkney Active Network Management project

History and origins of the project

The Orkney Active Network Management (ANM) is an innovative approach for managing renewable connections to the distribution network that was developed on the Orkney Islands in the North of Scotland. The electrical distribution network on the Orkneys serves 11,500 customers, with a minimum demand of 8 MW and a maximum demand of 31 MW. The islands are connected to mainland Scotland by two 33 kV submarine cables, each providing an import/export capacity of 20 MW (Kema, 2012).

The Orkneys have considerable potential in terms of the development of renewable energy resources, particularly wind, wave and tidal energy. It has established itself as a key location for tidal and wave energy development and is the home of the European Marine Energy Centre, which fully tests marine generation technologies (with a grid connection). Renewable energy has become a key local industry and a significant investment in renewable generation has continued (OREF, 2014).

Figure 5: Location of the Orkney Islands within Scotland



The project is in reality several projects that came together and producing an innovative solution to a local problem. The project's inception goes back to 2005, when the UK's Department of Trade and Industry (DTI) supported academic research at the University of Strathclyde in Glasgow that examined possible alternatives to physical network reinforcement for connecting renewable generation sources to distribution network (Currie et al., 2007).

The academic research focused mainly on the division of networks into zones with export and import limits and the design of a system that controlled and automated curtailment of generation from additional distributed sources and enable its connection without having to upgrade the physical network. A significant proportion of the research initially was also concerned with modelling the degree to which renewable generation sources would need to be curtailed in order to keep the network within its mandated safety parameters. Interestingly, this modelling was not restricted to engineering concerns and also included modelling of the economic impact of curtailment on generators (Kema, 2012).

The move from this generic modelling and engineering work to the practical application of the technology was another very important step for the project, but one that took around 6 years and significant financial and regulatory support from the regulator, Ofgem, as well as significant commitment by the local DNO, SSEPD and a high degree of local involvement and interest from small-scale renewable generators (Kema, 2012). Many of the generators that were successfully connected to the network as part of the scheme are owned by local community groups and their benefits have accrued locally.

Although these ideas were not developed entirely in the Orkney niche, they were first applied there. In the specific context of the Orkney Islands, this technological approach was successful at enabling substantial additional generation which would otherwise have required an additional sub-sea cable to mainland Scotland at an estimated cost of £30 million. For the sake of comparison, the Orkney ANM project cost £500,000 according to project documents (Kema, 2012).

Drivers and objectives

Many documents relating to the Orkney ANM project have been published since its inception. These naturally evolve and change to mirror changes in the project, but their description of the drivers and objectives behind the implementation of the ANM technology remain remarkably consistent. The main driver is that distribution networks have not been designed to accommodate large number of generator connection, and under traditional approaches, the only way to connect additional renewable generation would have been massive investment in the Orkney network infrastructure, including the installation of an additional sub-sea cable to the mainland. Many of the project documents argue that the goal of connecting additional renewables without upgrading the physical network has been achieved, creating benefits in terms of carbon emissions (Currie et al., 2011) and allowing relatively rapid connection of distributed generation at no additional cost to the DNO (Kema, 2012).

Modularity was highlighted as an important feature of the proposed solution – and this modularity was exemplified in the division of the network into multiple self-regulating control zones of varying sizes and levels that had clear rules governing their boundaries and interactions (Currie et al., 2008). Some of the zones were nested within other zones, and they largely corresponded to geographical features and to network topology. This modular design enabled the scheme to be expanded gradually, and tested at a smaller scale before implementing the next level, and the geographical features of the Orkney archipelago, with its two cable connections to the mainland, made this modularity a natural choice.

The main aim of Orkney ANM trial is presented as the facilitation of connecting renewable and distributed generation sources to the distribution network in the Orkneys, an objective that is specific and linked to a particular location. Earlier documents relating to the project emphasize the term “Active Network Management” and do not mention smart grids at all. It appears that, prior to 2008, the project was not explicitly linked to a wider smart grid narrative. Currie et al. (2008) describe the “philosophy” of the ANM technology as being preventative and corrective – it manages the network to ensure that power does not push the network below or above operating limits, but also automates the process of responding to any breaches of those parameters. This emphasis on automation is something it has in common with many visions of smart grids, but this link was only explicitly made several years after the inception of the project.

Creation of the niche

The multi-level perspective is a helpful tool in understanding the dynamics of innovative niche projects such as the Orkney ANM and its influence on the wider regime. Although the MLP is most often used to analyse historical case studies, it has also been used to analyse policies supporting niche formation and regime change, particularly by Kern (2012), who devised a framework of analysis of policy impact at the niche, regime, and landscape levels. This framework loosely guides the analysis of this case study.

Before examining change at the niche level, it is also worth exploring briefly how the niche was created in the first place, and the factors that stabilised it and its actor configuration. The ideas behind the ANM technology now driving the Orkney network originated from research at the University of Strathclyde. The research focused on devising ways of enabling the connection of additional generation without network reinforcement, and modelling the impact of the inevitable restriction on generation on the economic viability of distributed generation.

Naturally, this research did not take place in a vacuum and was linked to other actors and projects, however, the scope of the paper is such that this will be defined as the nucleus around which the niche developed. The Strathclyde team working on ANM collaborated with one of the DNOs, SSEPD, and bid for additional research funding from the DTI in 2004. At the time, there was very little direct investment in network innovation by Ofgem, but many of the funding schemes for innovation were about to become available.

The DTI funding study and modelling led to the partners, the DNO and University of Strathclyde, with some involvement from local actors, created an initial specification for the ANM project and this formed the basis of an application to designate the Orkney Islands as a Registered Power Zone (RPZ), which meant that the project could get funding from Ofgem through this scheme in 2005 (Currie et al., 2008). Follow that, the project got additional innovation funding through Ofgem’s Innovation Funding Incentive (IFI) in 2006, and continued to enjoy support from Ofgem since.

It is clear that a number of factors led to the development of the Orkney ANM niche. The drive to invest in the islands’ potential for renewable energy generation, and the identification of the distribution network as the main barrier for that has been important, but so has the relevant academic research and the long-standing cooperation between university researchers and the local DNO (Kema, 2012). The geographical isolation of the islands and the involvement of the local community and local generators has also been a factor in supporting the unique niche that developed.

All these factors made the creation of the niche possible, but the financial support from Ofgem, and the designation of the Orkneys a Renewable Power Zone injected financial resources into the niche that made greater experimentation and development possible. It also gave niche actors a greater claim to legitimacy (and important resource for new projects). Additionally, Ofgem had an important role as a neutral mediator who supported the development of new innovative market mechanisms and contractual arrangements that break with existing industry models. Without this support it would have been very difficult to connect additional generation to the Orkney network, even with the ANM technology in place. The regulator was also instrumental in mediating and facilitating the agreement on a framework for curtailment that was perceived as being fair and transparent to all participants, particularly generators (Kema, 2012).

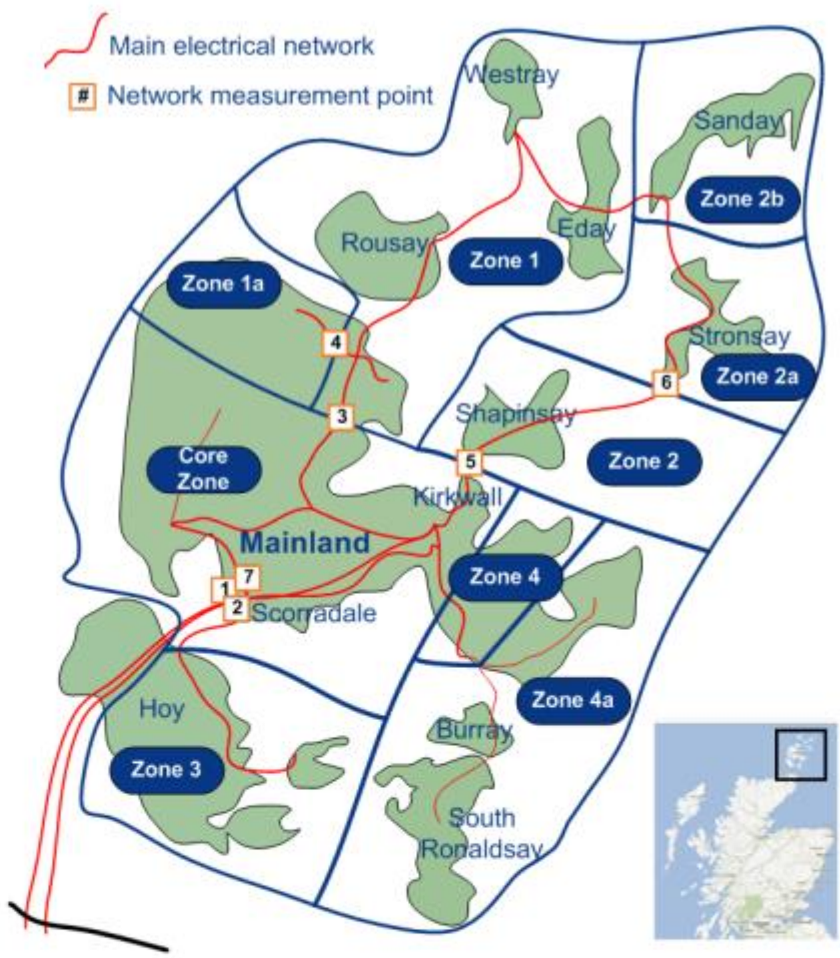
The location and history of work in Orkney is mentioned as an important driver for further investment in the island. This is compatible with the idea that a niche, once established, can become a driver of further related innovations than can change the wider regime (Foote et al., 2013).

Niche processes

A number of processes within the niche are valuable for understanding the complex innovation activity taken place within it. These operate on multiple levels and interact and include learning, changes to technology, formation of new business models and institutions and the creation of new relationships between actors. All of these processes have taken place to varying degrees within the Orkney ANM niche, which has helped in refining the ANM technology, and the economic and systemic aspects of its use. This section will discuss some of these developments and show their evolution within the niche.

From a technical perspective, the ANM scheme applied two novel ideas to managing the distribution network. Firstly, it divided generation into firm generation that cannot be curtailed and non-firm generation that can be curtailed automatically if needed in the case of a network fault, and regulated non-firm generation, which can be trimmed or tripped depending on the prevailing network conditions. Secondly, the network is divided into a number of zones with measuring points that determine the level of export and import between these sub-networks. Within each sub-network there is a degree of regulation that is implemented by trimming or tripping non-firm generation, based on demand, local generation, and import/export (Currie et al., 2007; Macleman, n.d.).

Figure 6: Schematic representation of the Orkney ANM system



Source: ANM Live page, http://anm.ssepd.co.uk/ANMGen.aspx

These two features of the ANM represent a departure from the traditional approach to connecting distributed generation, which calls for upgrading the physical distribution network to increase its capacity. Instead it seeks to collect data on the state of the network, including demand, faults, export and import, and generation levels. It then dynamically uses that data to reduce or cut off generation if certain thermal safety limits are approached (Currie et al., 2007; Currie et al., 2008).

By 2013, there was a substantial progression in the project in terms of the confidence in the ANM technology as well as a refinement in its definition. Additionally, there was a shift in language from the earlier days of the project, with a greater emphasis on the ANM being part of wider transition to smart grids (Foote et al., 2013), something that was not very prominent in the early days of the project. This indicates that the learning processes within the niche have led to the construction of a clearer conception of the technology and its use.

One advantage of niches in terms of the development of new technologies is that they expose unexpected problems and challenges in the implementation of the technology. One such problem has been the issue of the reliability of communications networks. The fail-safe design has meant that communication disruptions would result in trimming and curtailment of generators. The use of BT private lines, which were initially expected to be the most reliable mode of connection, resulted in multiple failures and unnecessary curtailment of generation. Interestingly, the ways the system boundaries are defined means that the communications technology was the responsibility of the generators and not the ANM scheme formally (Kema, 2012). However, it is possible that generators would blame the ANM scheme if they lost revenue as a result of communication failure.

As smart grids proliferate, communications may have to become an integral part of the electricity network or at least an important concern for those operating the network. Standards and connections modes with high reliability and redundancy may become an important feature of smart energy systems, which is a departure from the traditional scope of the electricity network, but also from the way ICT network operate (in particular IP-based networks such as the internet). The new set of needs and skills at the nexus of network operations and ICT technology will create new networks of innovation and new socio-technical arrangements that will likely characterise the emerging field of smart energy systems (Kema, 2012).

Another interesting development has been the creation of a spin-off company involved in the diffusion of ANM technology to other contexts and in developing the technology further. The company also acts as a carrier that diffuses what has been learned in the Orkney Islands niche. It is already involved in implementing it in different contexts, including the Shetlands as part of the Northern Isles New Energy Solutions (NINES) project and Low-Carbon London, another smart grid demonstration project funded by the LCNF (Kema, 2012), and has been growing rapidly, recently opening an office in the US (SGS, 2014). Many of the more recent documents relating to the Orkney ANM highlight Smarter Grid Solutions as a key partner in delivering and developing the project further (e.g. Foote et al., 2013).

The application of technical design ideas to a specific location, and with specific local partners enabled the development of a wider institutional and economic framework that makes the technology viable and useful. For instance, it made it possible to ask question about what it would take for generators to agree to give up control on their generation output and allow it to be automatically curtailed by the system. Another relevant question is that relating to those financing generation, and what they would require to agree to curtailment as proposed by the scheme. A significant part of the early work on the project was dedicated to modelling the levels of curtailment for generators in order to answer such question. The attention paid to analysing possible curtailment was in a way one of the key innovations within the niche as it gave generators the predictability they needed to make decisions about their connection, and gave them the legitimacy to ask for finance under an unusual arrangement that may have otherwise been seen as too risky (Currie et al., 2007; Kema, 2012).

Directions for the future

More recently, SSEPD and Smarter Grid Solutions have been involved in trying to find ways to improve the ANM scheme to get a better utilisation of the network. Generators are also keen on this, because it means less curtailment, potentially, and greater revenue and share of generation for them. A number of areas of immediate potential improvement have been identified, the most prominent is the communications system, within which any failure results in fail-safe curtailment. The failures in communications systems were not very frequent, but happened often enough to contribute significantly to curtailment of generation in a review of the project from 2010 and2011 (Foote et al., 2013; Kema, 2012).

Another potential development that has appeared frequently in documents discussing the project is that move from a funded trial to a viable and self-sustaining system. This transition, the paper argues, is necessary for ANM to become self-sustaining and mature as a market. The costs of an ANM scheme are lower than the cost of traditional network reinforcement. However, the innovation process that has led to the creation of the Orkney ANM also sheltered it from the need to develop a long-term business model to finance the technology (Kane & Ault, 2013; Kema, 2012). Developing the appropriate business models and charging structure for the use of the ANM technology is another important issue and has been addressed in several publications, with a suggested mode based on a combination of connection charges and use of system charges, a structure similar to that currently applied to the distribution and transmission networks in the UK (Kane & Ault, 2013; Kema, 2012).

There is also an indication that Smarter Grid Solutions is acting as a main information broker that is accumulating knowledge from multiple smart grid projects and using that collectively to improve the technology (Foote et al., 2013; Kema, 2012). The recent expansion of the company into the US market, and its involvement in additional projects in the UK indicates that it may have an important role in diffusing the technology.

The ambition to expand the scheme in terms of scope, technology and reach is apparent in many of the more recent documents discussing the project. There is a desire to introduce greater voltage monitoring, and allow the ANM software to take that into account while managing the network load. The team has also established an energy storage park in which generators can trial different types of energy storage to examine their impact on the network, and compensate for curtailment. (Foote et al., 2013). The constellation of actors, knowledge and infrastructure that has evolved on the Orkney Islands has made this experimentation with additional related technologies possible.

Dynamic line ratings are another potential evolution of the technology. The line ratings used to estimate network thermal limits are normally seasonal averages that don't take into account weather conditions such as wind, temperature, and solar radiation that affect the thermal limits of the network. This means that these limits are often very conservative. A future innovation within the project is to create a dynamic line rating application that monitor the temperature of a given line in real time (rather than estimating the value based on current and the line rating). This means that curtailment only takes place when the temperature actually reaches the limit. This information is communicated through a low-power radio link to the ANM system (Michiorri et al., 2011; Kane & Ault, 2013). This is an interesting application of a smart grid. Weather data, generation data, and real time monitoring can be used together to improve the efficiency of the network and remove slack in the system. This process of using disparate data sources to improve operations is likely to be at the heart of smart energy system

Another potential extension of the ANM system is using to support the creation of a number of markets based on storage, demand response, or curtailment order. A demand response market is most likely to benefit consumers and compensate them for some of the costs of the scheme, that will ultimately be passed on to them. Distributed generators may benefit from trading curtailment events, offering to curtail their generation on behalf of another generator and allowing potentially more beneficial curtailment arrangements. Finally, it is suggested that a market for ancillary services based on storage or demand management (albeit one that is not very well defined yet) may help finance the running of the ANM scheme in the long term, rather than depending on access and use of system charging. Demand response is likely to be see significant development due to the requirement for DNOs to find ways of providing demand response incentives to consumers (Currie et al., 2008)

One suggested innovation in this paper is targeted at resolving the problem of choice of non-firm generation to curtail if and when the need arises. At the time of the papers' writing, the method used was 'last-in-first-out'. This means that the generator connected to the network last, would be curtailed first. This has been used for its simplicity and transparency and because it does not have a negative effect on those already connected. However, the engineers working on the project argue that it is not optimal from economic or electrical design perspectives. To address this, they respond with a suggestion for some innovations in the way curtailment takes place- these include a pro-rata system to ensure that all are curtailed proportionally or a market system where curtailment is traded, or a rota system, or a system that optimises technical (network) performance, or one that optimises emission reductions (Kane & Ault, 2013).

The introduction of demand response is another important priority for the development of the ANM technology as it could potentially allow lower curtailment rates and improve the operation of the network (Kema, 2012) Organisations like Community Energy Scotland, have been encouraging the use of demand response solutions to create flexible loads that can draw power from the network when there are high levels of renewable generation as an alternative to curtailment. This is likely to be accepted more readily on the Orkneys because of the tangible direct benefits to the local residents (Foote et al., 2013). More generally, demand response is a seen as key benefit of the smart grid, and developing the technology and associated business models within niches like the Orkney ANM is an important step in the technology being adopted more widely.

Conclusion

The study of innovation is challenging, partly because innovations are created in complex and dynamic interactions that are difficult to analyse. The lack of a single, unified, theory of innovation and the difficulty of defining the boundaries of emerging technologies and sociotechnical systems also pose a significant challenge. To address these challenges, the aim of the research on which this paper reports is to conduct an in-depth investigation of specific demonstration projects or pilots in order to understand how innovation in technologies and their associated business models and institutions arise . The ultimate aim of this research is to provide insights into the role of policy in fostering smart grid innovation, and how different actors can benefit from their involvement in the smart grid market, and use those insights to contribute to a better theoretical understanding of innovation and transition processes.

In terms of findings, the research so far points to a few. Firstly, the change in the regulatory framework for electrical distribution in the UK has created a flurry in innovative activity in the last 10 years. Secondly, funding demonstration projects has been effective at fostering a more sociotechnical approach to innovation that helps develop business models and institutional frameworks, rather than simply focusing on technical R&D. Finally, there remains a gap between fostering successful niche innovations, and that innovation being diffused more widely and finding ways of supporting that process of diffusion remains a significant challenge.

The Orkney ANM provides an example of a successful niche that has demonstrated the potential of smart grid technologies. This niche would not have existed without explicit financial support and legitimization by the regulator, Ofgem. However, the regulator's support was not the only factor and a constellation of contingent conditions relating the local community, existing investments in renewables, and the availability of academic research and engineering skills were also important. While the ANM demonstration on the Orkneys was a success, it is still uncertain how this will result in change at the regime level. The creation of a spin-off company, Smarter Grid Solutions, to commercialise the technology and lessons learned from the project suggest one likely mechanism for diffusion from the niche.

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