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How to cite:

Langendahl, Per-Anders; Cook, Matthew; Potter, Stephen; Roby, Helen and Collins, Trevor (2016). Governing effective and legitimate smart grid developments. *Proceedings of the Institution of Civil Engineers – Energy*, 169(3) pp. 102–109.

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Version: Accepted Manuscript

Link(s) to article on publisher's website:
<http://dx.doi.org/doi:10.1680/jener.15.00026>

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Governing Effective and Legitimate Smart Grid Developments

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Words: 5224

Abstract

Smart grids which use Information and Communication Technologies to augment energy network management have been developed in several locations including London and Stockholm. Common rationales for smart grids include: de-carbonising energy supply, maintaining security of supply and promoting affordability. However, beyond these general abstractions, smart grids seem to exhibit considerable diversity in terms of their characteristics and rationales for development. Thus, while the term smart grid may imply abstract notions of what smart grids are and might do, they are developed in response to local contingencies and diverse. In this paper we therefore explore the governance processes through which smart grids are constructed. The paper suggests that standardising smart grids through definitions and best practices that fix both problems and solutions should be avoided. Rather governance processes should be promoted in which local contingencies can be articulated and more legitimate smart grids developed in response to these.

Keywords: Energy; Sustainability; Social Impact

1. Introduction

Sustainable energy futures have been promoted in many locales and smart grids often form a foundational component of these. A smart grid is an advanced network infrastructure characterised by a two-way flow of electricity, and information about electricity consumption, between electric utility firms and consumers (Farhangi, 2010; OECD & IEA, 2011). As such, the traditional electricity network architecture is replaced by a more integrated system architecture (see Figure 1) that is flexible, efficient and able to cope with new challenges, such as increased electricity consumption and uptake of intermittent and renewable electricity generation.

Figure 1 represents a simplified illustration of both traditional grid and smart grid. A traditional grid is typically characterised by its one-way flow of electricity from centralised electricity production in large power plants through the grid to electricity customers. A smart grid is one that is capable of integrating new forms of energy generation (e.g. distributed and renewable electricity sources) and enable consumers to generate their own electricity and supply surplus electricity to the grid (Blumsack and Fernandez, 2012). This requires the grid to accept two way power flows, particularly at the local and district level. Within smart grids, Information and Communication Technologies (ICTs) can be thought of as providing an additional layer to existing network infrastructure, allowing information about electricity consumption to flow between various actors linked to the smart grid (Erlinghagen and Markard, 2012). For example, smart metering and control systems are typical smart grid components that use software applications and can be used by network operators to automate aspects of electricity distribution networks and enable remote access to customer meter readings.

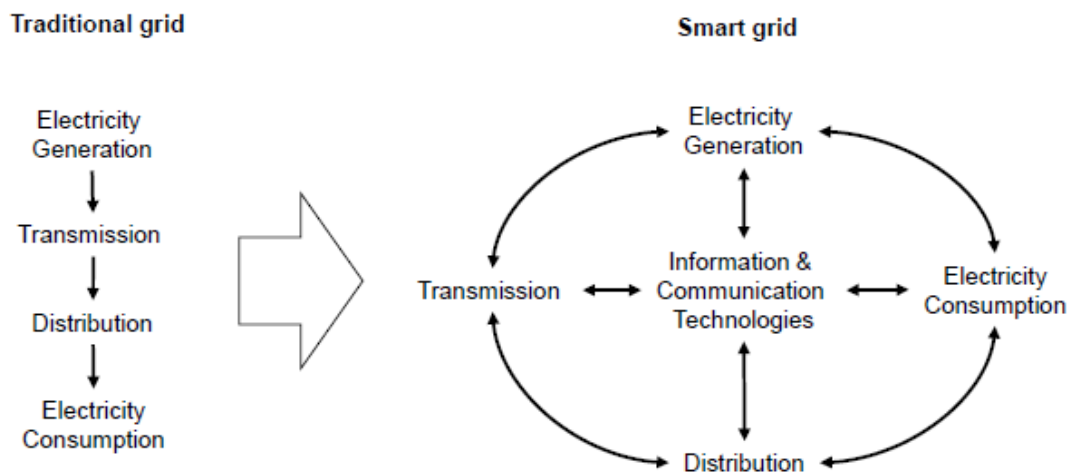


Figure 1: Traditional and smart grid architecture

Smart grids are expected to change the way electricity is generated, transmitted, distributed and consumed (OECD/ IEA, 2011). Indeed, smart grids may change the roles and

responsibilities of the various energy actors, such as distribution network operators, energy firms who both generate and supply electricity, and electricity customers. Smart grids can also create opportunities for new business models to augment energy network management (e.g. demand response and energy storage possibilities) and cope with new forms of energy demand, such as electric vehicles (Giordano and Fulli, 2012; Fisher, 2010).

At a policy level, smart grid developments are often initiated for strategic goals such as to decarbonise energy systems and ensure secure and affordable energy supplies (DECC, 2014). To achieve such goals, many commentators emphasise a need for governments and industry to establish protocols, definitions and standards for smart grid developments (OECD/IEA, 2011; NIST, 2010). Standards are developing through national and international collaborations, such as the National Institute of Standards and Technology (NIST) in the United States and the Joint Working Group for Standardisation of Smart Grids in Europe. Standards are also proposed in a number of smart grid areas such as advanced metering infrastructure, demand response and integration of renewables as well as electric vehicles on distribution network (NIST, 2010).

Standards can be useful for smart grid developers (e.g. Electrical equipment manufacturers, electric utility firms and ICT industry) to achieve interoperability between the electricity network system, smart grid devices and applications. As such, standards may help to further accelerate smart grid developments while reducing the costs of these. However, at the local level smart grids exhibit considerable diversity in terms of their characteristics and rationales for implementation (Cook *et al.*, 2014). For example, they are implemented to integrate and balance renewable electricity generation, to manage peak electricity demand, and to delay or replace the need for network reinforcement, e.g. avoiding the need for more cables and associated infrastructure.

Indeed, a multiplicity of smart grid developments are underway, each emphasising different characteristics and rationales for development and implying that there is neither a widely accepted smart grid definition or blueprint which is simply applied. Therefore the term smart grid appears to be used as a somewhat empty signifier of semiotic theory. While it contains some abstract notions of what a smart grid is and might do, it is also constructed in response to local contingencies. These may reflect local energy management priorities, such as ageing network infrastructures, increased electricity demand, power plant closure, and implementation of intermittent and renewable electricity generation. However, there is a paucity of research on how smart grids are developed and the effects of local contingencies on these complex processes.

In order to begin to address this gap in knowledge, this paper conceptualises smart grid development processes from a governance of innovation perspective. Following Joss (2015)

the governance of innovation is defined as a process involving the mechanisms and processes of steering, co-ordinating, facilitating and justifying smart grid developments. Drawing on Healey (2007) from the spatial planning literature, this paper also recognises that smart grids and associated governance processes proceed in particular locations. Smart grid developments consist of multiple actor processes that take place in various institutional arenas situated in formal (e.g. negotiation with regulator) and informal (e.g. project team meeting rooms) institutional landscapes. Within such processes, actors make sense of the context in which smart grids are developed, and identify responses to challenges emphasised, such as the need to integrate renewables. Crucially this is a collective sense making process through which ideas are generated and mobilised.

This paper therefore explores the governance processes through which smart grids are constructed in various locales. It focuses on the development of demand side response initiatives (DSR) in particular, which are a key element of smart grids (DSR initiatives are defined below). The paper is structured as follows, section 2 presents the findings from case study research on smart grid initiatives, with particular reference to DSR, in the United Kingdom (UK) and Scandinavia. Section 3 provides a comparative analysis between the selected initiatives and presents the results in terms of differences and similarities between them. Finally, Section 4 concludes with a discussion of the results from case study research, offers a contribution to understanding governance of smart grid developments and sets out future research directions.

2. Exploring DSR in smart grid developments

This section draws on case study research undertaken to explore smart grid initiatives in various locales (see Table 1). Smart grid initiatives in the UK and Scandinavia were selected because significant activities in terms of government support for, and investment in, smart grid developments are promoted in these national contexts (Giordano, Meletiou and Covrig, *et.al.* 2013). In the UK, the Low Carbon Network Fund (LCNF) was a £500 million fund established by the UK government. Between 2010 and 2015 it supported several smart grid initiatives undertaken by Distribution Network Operators (DNOs). At the same time, governments in Sweden and Denmark supported smart grid projects undertaken by electricity utility firms on distribution networks.

Smart grid developments with DSR components formed the focus of case study research. DSR was selected since it forms part of many smart grid projects and is emblematic of the trend to decentralised energy systems. DSR initiatives typically include actors such as electricity utility firms (e.g. transmission system operator and distribution network operators) who engage with their customers to adjust their electricity demand at particular times. For example, a major electricity customer (e.g. industrial and commercial) can reduce their electricity demand as requested by the utility firm by turning down or off electric equipment,

e.g. heating, ventilation and air-conditioning. Customers with standby generators can use these to generate electricity to meet their own electricity needs during a response and export electricity to the grid.

In the UK, relationships between electricity utility firms and their customers are often deepened by commercial firms commonly referred to as aggregators. These firms operate in the UK energy market and specialise in aggregating DSR capacity. To date, aggregators in the UK have generally supplied DSR capacity to the National Grid who use DSR as an ancillary service to balance electricity supply and demand. More recently, aggregators have been invited by regional Distribution Network Operators (DNOs) to support emerging DSR initiatives on their networks. In the UK, DNOs own and operate the network infrastructure that distributes electricity to customers. In contrast, commercial aggregators are not well established in Scandinavia. However, increased uptake of intermittent and renewable electricity generation and the need to balance these, may lead to development of such firms in Scandinavia (Linnarsson et al., 2013).

Case study research was undertaken to explore and compare a variety of smart grid projects in the UK and Scandinavia, with particular reference to DSR (please see table 1 below).

Table 1: Selected Smart grid projects

Smart grid initiative	Project lead	Locale	Project Status
FALCON	Western Power Distribution	Milton Keynes, UK	Started 2011 and completed September 2015
Low Carbon London (LCL)	UK Power Networks	London, UK	Started 2010 and completed December 2014
Capacity to Customer (C2C)	Electricity Northwest	Manchester, UK	Started 2011 and completed in August 2015
Smart Grid Gotland	Vattenfall	Gotland, Sweden	Started 2012, ongoing until December 2016
EcoGrid EU	Energinet.DK	Bornholm, Denmark	Started 2011 and completed in August 2015

These smart grid initiatives detailed in Table 1 were selected as they share a number of common features, they:

- are led by utility firms and undertaken on regional distribution network level to which the majority of electricity customers are connected
- are supported by national governments

- are undertaken under a five year period between 2010 and 2015, except the initiative on Gotland that finishes in 2016
- included DSR trials with findings recently published in the public domain

The selected smart grid initiatives were explored and compared to reveal how such developments proceed in various locales and different national contexts. Consistent with exploratory case study research, key issues that warrant further investigation were identified (cf. Robson, 2011). Following the governance perspective and the research approach outlined above, each smart grid project was explored with the following questions in mind:

- Who are the proponents of the smart grid project and what are they trying to achieve in each locale?
- What are the motives to develop DSR?
- What challenges associated with DSR have they identified?
- How have these challenges been overcome?

Data were collected from multiple sources using multiple methods, e.g. attending smart grid events and reviewing project reports and podcasts available in the public domain. Guided by the questions detailed above, an understanding of each smart grid project was developed. Themes to facilitate a comparative analysis identified differences and similarities between the selected smart grid projects and include:

- the purposes of smart grid projects expressed as project aims and objectives,
- local energy management priorities,
- DSR activities and actors involved, and
- enabling DSR futures.

Findings from each case study are detailed below.

2.1 FALCON

Running between 2012 and 2015, this £16m smart grid project was led by Western Power Distribution (WPD). The aim of this project was to investigate how new techniques (e.g. DSR, energy storage and dynamic asset rating) worked in practice to determine their applicability to manage the 11kV distribution networks in future scenarios (WPD, 2015). This project took place in Milton Keynes, which does not currently suffer from network overload. However, increases in network load due to new housing developments and the uptake of low carbon technologies (e.g. electric vehicles) may put the network under pressure in the future. A DSR pilot scheme was therefore developed and trialled in this project to address these issues.

DSR can be used on the 11kv substation to ensure that the load profile is kept below the network capacity. Major electricity customers such as organisations involved in logistics, higher education, water utility, district heating and health care were contracted to provide DSR by reducing load or generating electricity. Organisations participating in the trials were recruited via aggregators or directly by the DNO. The recruited organisation were contracted to reduce their electricity demand during times of network peaks. Smart meters capable of 1 minute reading intervals were installed at the customers' point of connection to the 11kv to allow DSR events to be measured in detail. This project showed that DSR can be used by a DNO to manage load profiles on the distribution network rather than having to invest in network reinforcement.

A challenge identified in this project was that DSR on distribution networks may have to compete with other DSR schemes, e.g. the National Grid's DSR schemes. In response, project participants initiated industry negotiations, notably between DNOs and the National Grid, to promote interoperability between the different DSR schemes available. Another challenge identified was that the 11kV network may not have sufficient capacity to operate DSR effectively. This was mainly because organisations with DSR capacity may be too few in numbers at this scale. To overcome this challenge it was suggested that DSR at higher network scales (i.e. 33kV and 132kV) would be more effective. A higher network scale covers a greater geographical area and is likely to have a critical mass of organisations that can provide DSR. Furthermore, the cost of reinforcing distribution networks increases with voltage levels and therefore deploying DSR at 33kV or 132kV may be more applicable and commercially viable for a DNO.

2.2 Low Carbon London

This £28m smart grid project was led by UK Power Networks in London. The project aimed to develop and test various techniques (e.g. DSR) that could help a DNO to manage electricity distribution networks in London and other cities (UK Power Networks A, 2014). In London, UK Power Networks faces the critical challenge of increased electricity demand, while finding it difficult to reinforce the electricity network infrastructure as London is a densely built and populated region where network reinforcement can be costly and disruptive. DSR was therefore viewed as an important aspect of smart grid developments that could help avoid or defer reinforcement measures in the city.

DSR from both domestic and commercial network customers was sought in this project. DSR from domestic customers required smart meters fitted with In Home Displays to be installed in selected households in the city. An electricity supplier was engaged as a partner in this DSR initiative and facilitated smart meter deployment. The smart meters provide domestic actors with a dynamic tariff that incentivises them to reduce energy consumption during times of peak load.

DSR from commercial customers was based on contracts with major electricity users who were paid to provide DSR by reducing demand or generating electricity during network peaks. Aggregators were engaged as partners to co-develop the DSR scheme for this project in collaboration with the DNO and to recruit commercial participants to the trials.

Given contextual factors, such as high land prices and the disruptive effects of reinforcing a network in a major city, this project showed that DSR may be a valid alternative to network reinforcement in this and similar locales. Unlike Milton Keynes, London is a large and densely populated city where the 11kV network has a critical mass of organisations connected to make DSR viable at this scale.

2.3 Capacity to Customers

This £10m smart grid project was led by Electricity North West. This project aimed to increase the capacity of the network to defer reinforcement and support fault management (Electricity North West, 2015). This project was situated on the high voltage distribution network in the Manchester region. This region includes densely populated areas, industrial and suburban areas, as well as rural areas north of Manchester. In this project, DSR was developed and tested to manage fault recovery. This form of DSR enables the DNO to defer reconnection to contracted customers when a fault occurs on the network. Electricity supply is reinstated when the fault is resolved. This is a very different rationale for smart grid developments to those explored in FALCON and LCL, which focus on network peak management.

Industrial and commercial customers were recruited and contracted to provide DSR capacity in support of fault recovery. Interestingly, the contractual arrangement of DSR formed part of the connection agreement between the DNO and its existing and new customers.

Aggregators were also involved in this project as third party actors to recruit participants to the trials and secure managed connection agreements between the DNO and its customers. Unlike FALCON and LCL, aggregators are not needed to manage DSR used for fault recovery, because in this form of DSR, the DNO defers the reconnection of electricity supply to contracted customers - an activity where direct relationships between the DNO and its customers is preferred due to the need for rapid responses at unpredictable times. However, the work of aggregators to help secure DSR contracts between the DNO and its customers may still be needed to enable such DSR activities.

A key challenge identified in the C2C project was to recruit customers who were both able and willing to provide DSR. A particular focus on the contractual arrangements between the DNO and its customers was developed to meet this challenge. Here the smart grid project proponents noted that the contractual arrangements have to be developed in light of

customers' ways of working. Contractual features included payment arrangements, how often the network customer is likely to respond in a year, as well as the duration of response.

2.4 Smart Grid Gotland

This is an ongoing project in Sweden led by the energy company Vattenfall. This project aims to identify measures to enable the integration of renewable electricity generation into the distribution network on the island (see www.smartgridgotland.com). Since renewable electricity generation (e.g. wind power) is intermittent DSR is deployed to help balance electricity generation and demand. DSR can be used to steer electricity demand towards peak production and vice-versa. This island location offered a good context to test various aspects since Gotland is representative of Sweden: it has a similar mix of industrial and residential electricity users.

A group of domestic customers was selected to provide DSR. Smart meters were installed in homes to inform these customers about energy use and test how dynamic price signals can be used to steer electricity consumption. However, since dynamic price signals may have little effect on the latter, automated forms of DSR were also tested. As well as providing dynamic price signals, the smart meter was also used to control loads resulting from central heating and hot water use. Unlike DSR initiatives in the UK, aggregators did not identify and recruit customers to the trials. Rather, DSR is developed by DNOs in collaboration with electricity suppliers who engage domestic customers.

2.5 EcoGrid EU

This smart grid project in Denmark was led by Energinet.DK in collaboration with various partners (e.g. ICT firms and a local grid company). This project aimed to develop market solutions and to use ICTs to integrate renewable electricity generation (e.g. wind, solar and biomass) into the energy system (see www.eu-ecogrid.net). In the present energy system, supply side actors (e.g. transmission and distribution network operators) are responsible for maintaining the consistency of electricity supply. The project investigated how flexible electricity demand can be mobilised and used to balance electricity supply and demand in energy systems. The project proceeded on the island of Bornholm, which provided the context to test system balancing on a large scale.

DSR was trialled in this project to explore how such measures can promote flexible electricity consumption. Smart grid project proponents emphasised the need for smart meters with feedback systems to be installed in households. Such systems are used in this project to inform and motivate domestic customers to adjust their electricity consumption in response to price signals. Flexibility of demand was also managed through domestic appliances (e.g. heat systems) connected to the energy system. For example, a heat pump can stop if a power line is overloaded, an electric vehicle can adapt its charging patterns to support balancing of renewable electricity generation.

Similar to the smart grid project on Gotland above, this project suggests that DSR from domestic customers is needed to integrate renewable electricity generation; DSR must be implemented so as not to constrain everyday activities of domestic actors.

3. Comparative analysis

This section presents the comparative analysis and identifies differences and similarities between the selected smart grid initiatives described in the preceding section.

3.1 Purpose

The overall aim of all the selected smart grid projects was to develop and test new techniques to operate and maintain distribution networks in order to secure low carbon futures. Such futures are likely to entail increased electricity demand due to new loads (e.g. electric vehicles and heat pumps) as well as reversed and intermittent power flows from renewable electricity generation, e.g. wind and solar photovoltaic. DSR was deployed in these projects in order to involve demand side actors in electricity network management. However, although the overall aim of testing new techniques was the same for all projects, the purpose of DSR varied between the smart grid projects in the UK and Scandinavia. While the need to integrate renewables was recognised in the UK case studies, DSR initiatives were mainly deployed to manage network constraints and defer or avoid network reinforcement in these projects. In contrast, the stated purpose of developing DSR in the Scandinavian cases was to balance renewable electricity generation.

3.2 Location

Local energy management priorities influenced the smart grid development projects. The need to integrate renewable electricity generation shaped the Scandinavian smart grid projects. In contrast, the UK smart grid projects were influenced by a different set of energy management priorities, which included the need to avoid network reinforcement. For example, the DSR pilot scheme in FALCON was developed as an alternative to engineering techniques to avoid or defer network reinforcement. However, it was difficult to secure a critical mass of DSR capacity at the 11kV scale in Milton Keynes. Rather, in this region, DSR appears to be more suitable at a higher network scale (e.g. 33kV and 123kV) where DSR capacity and the cost of reinforcing the network is greater compared to the 11kV network. In contrast to Milton Keynes, findings from the smart grid project in London suggest that DSR on the 11kV network is commercially viable. This is mainly because land prices are high and sites to accommodate further infrastructure are scarce and expensive making DSR on the 11kV network more financially efficacious than in other locations. This locational aspect identified in London is likely to apply to other major cities. In such cities there may be a concentration of network customers with DSR capacities.

3.3 DSR activities and key actors

Activities associated with DSR and key actors involved in these varied between the smart grid projects. Four types of DSR activities were identified, namely: network peak prevention, fault recovery, dynamic tariff and balancing renewables.

- a) Network peak prevention refers to planned DSR actions as tested in FALCON and LCL and involved customers reducing their demand during networks peaks. This type of DSR can be used by a DNO to defer or avoid network reinforcement. Recruiting customers to reduce load or generate electricity was a key activity in these projects. In many instances, relationships between the DNO and major electricity customers were made by aggregators.
- b) Fault recovery refers to DSR activities that respond to faults on the network and was tested in the C2C project. It involved relationships between the DNO and major electricity customers with managed connection agreements. Aggregators were also involved to secure such agreements on behalf of the DNO. The managed connection arrangements between the DNO and customers allowed the DNO to defer the electricity supply to these customers when a fault occurred on the network. Contracted customers are restored at a later stage for which they are compensated.
- c) Dynamic tariff refers to DSR activities that aim to stimulate and steer domestic electricity consumption and was tested in the initiatives in Gotland, Bornholm and London. Key activities included the recruitment of domestic customers and the installation of smart meters in homes. Electricity suppliers were involved in facilitating the roll-out of smart meters and to send out dynamic price signals to customers via these. DSR involving dynamic tariffs were used in these projects to manage changes in demand on the distribution network and avoid network peaks.
- d) Balancing renewables refers to DSR activities aimed to balance renewable electricity generation to enable further integration of these. In the Scandinavian cases, domestic customers were recruited to the project trials to adjust their electricity demand in response to peak renewable electricity generation. Remote and automated control of domestic appliances (e.g. electric vehicles, central heating and water heating) were also tested to support balancing of renewables.

3.4 Enabling DSR futures

A common challenge identified across the selected smart grid projects was to recruit customers who are both able and willing to provide DSR. Related to this, the projects also recognised the need for implementing DSR without compromising household activities, business operations and customers' comfort levels. Commercial arrangements and associated models to enable DSR were developed in response to these challenges. In many

of the selected projects (e.g. LCL, FALCON), aggregators played a key role in identifying network customers, building relationships with them and recruiting them as energy partners. These aggregators also worked in collaboration with DNOs to co-develop DSR pilot schemes on the distribution networks. In DSR used for network peak prevention activities, aggregators may also play a role in managing these on behalf of DNOs and its customers.

Commercial arrangements were explored and tested in the selected smart grid projects to enable DSR. For example, the connection agreement, which is the conventional contract between the DNO and customers, formed the basis for DSR in the C2C project. In this case, managed connection agreements were developed and integrated with existing commercial and contractual arrangements. In FALCON, new contracts between the DNO and their customers were developed to enable DSR. These contractual arrangements were developed to conform with the existing DSR market and promoted interoperability between different DSR schemes, e.g. the National Grid and DNOs. The contract allowed actors to participate in FALCON as well as other DSR initiatives.

In dynamic tariff and DSR used for balancing renewables (e.g. Ecogrid EU and smart grid Gotland), smart meters are deployed to provide dynamic price signals to steer patterns of electricity demand. These smart meters can also be used to steer certain electricity loads (e.g. central heating and water heating) via automated controls. The latter is seen as important to balance renewable electricity generation and to enable the further integration of these.

4. Discussion and conclusions

This paper drew on case study research undertaken to explore and compare smart grid projects in various locales (e.g. London, Milton Keynes and Gotland) with a particular focus on DSR initiatives. Findings show that there are both common features of smart grid projects (e.g. securing low carbon futures) as well as specific features that are developed in response to local contingencies, e.g. the need to avoid network reinforcement or integrate renewables. Drawing on the comparative analysis discussed above a number of common characteristics between the selected smart grid projects were identified:

- 1) ICTs are variously deployed to better manage distribution networks;
- 2) DSR were developed and tested to promote low carbon futures, which is likely to entail increased electricity demand and renewable electricity generation; and
- 3) DSR involves electric utility firms working in collaboration with other specialised actors (e.g. aggregators, electricity suppliers, smart meter manufacturer) to engage demand side actors in DSR arrangements.

However, beyond these somewhat abstract notions and commonalities, the selected smart grid projects exhibit diversity in terms of their characteristics and rationales for implementation. Below we discuss this diversity in light of the four themes identified in the

previous section, i.e. purpose, location, DSR activities and key actors, and enabling DSR futures.

The purpose of the project expressed in terms of aims and objectives to develop and test DSR initiatives varied between the selected smart grid projects. For example, the purpose in the LCL and FALCON project was to test if DSR can be deployed on the 11kV distribution network to manage network constraints and avoid or defer reinforcement. The purpose in the C2C project was to test DSR as fault recovery. In contrast to the UK cases, DSR was developed in Smart Grid Gotland and EcoGrid EU to balance renewable electricity generation and to enable the further integration of these.

The location in which the projects took place differed. However, the analysis notes that smart grid developments are articulated to some extent in light of local energy management priorities. For example, difficulties in reinforcing networks in London make DSR from both domestic and non-domestic customers a valid and commercially viable measure. DSR was developed and used to address issues of reinforcement needs. In contrast, a key focus of the smart grid projects on Gotland and Bornholm was to use DSR to steer electricity demand towards peak renewable electricity generation. Thus, purposes of developing DSR are influenced, to some extent, by local characteristics and energy management priorities, which in turn determined the DSR activities and actors involved.

The DSR activities and key actors involved in the selected smart grid projects varied. For example, smart grid projects that trialled DSR for network peak prevention or fault recovery (e.g. FALCON, LCL and C2C), included DNOs collaborating with aggregators to engage industrial and commercial customers. Dynamic tariff DSR differed as domestic customers were engaged by their electricity supplier and asked to have smart meters installed in their homes.

As for strategies identified in the smart grid projects to enable DSR futures considerable diversity is noted. In DSR used for network peak prevention and fault recovery, commercial arrangements formed the basis of DSR initiatives. For example, the FALCON project emphasised contractual arrangements that allowed interoperability between different DSR schemes (e.g. the National Grid and DNOs), which was seen as a necessity to enable DSR on distribution networks. Contractual arrangements in the C2C project mattered too but for a different reason. DSR contracts in C2C were built on connection agreements between the DNO and its customers. DSR was integrated into such agreements and was developed to conform to the operations of the network customers participating in the trials. A key strategy to enable dynamic tariff DSR is to create forms of automated control which steer domestic electricity demand, e.g. central and water heating.

In conclusion, the research presented in this paper suggests that while at a high level of abstraction, smart grids exhibit common rationales and characteristics, in governance processes these are variously selected and emphasised in response to local contingencies. Thus standardising smart grids through definitions and protocols that emphasise certain characteristics and rationalities which must be present may stifle smart grid developments and should be avoided. Rather, smart grids should be treated as contextual and multifaceted phenomena, involving a variety of related techniques (e.g. DSR) that address a number of local energy challenges. For example, difficulties to reinforce networks in densely populated and built areas is a local feature that creates a distinctive rationale for DSR in major cities, e.g. London.

As the governance of sustainable innovation (including smart grid innovations) moves from apolitical niche experiments to more pluralistic public governance modes (Joss, 2015), governance processes should be promoted in which local contingencies (e.g. local energy management priorities) can be articulated and responded to. This more adaptive approach may require actors that lay beyond the traditional nexus of the electricity sector to be recruited to smart grid projects. Indeed, it may be crucial that, in order to promote legitimacy, the voices of these new actors are heard and make a difference to smart grids developments in each locale. As such, further research is needed that recognizes roles and responsibilities of various non traditional actors in smart grid developments.

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