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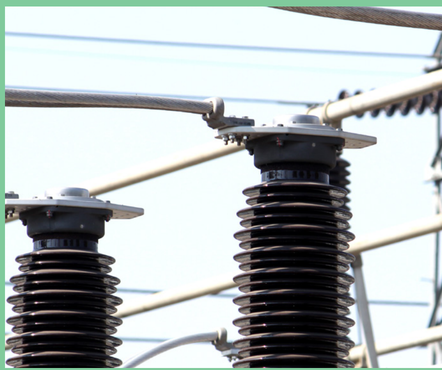

Scenarios for the Development of Smart Grids in the UK

Synthesis Report

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Executive Summary

Delivering energy more intelligently will be fundamental to decarbonising the UK electricity system at least possible cost, while maintaining security and reliability of supply. ‘Smart grid’ is a catch-all term for the smart options that could transform the ways society produces, delivers and consumes energy and, potentially, the way we conceive of these services. Smarter energy delivery is expected to be required to allow the integration of the expected growth in low carbon technologies and to be much more cost effective than traditional methods as well as contributing to economic growth by opening up new business and innovation opportunities. Innovating new options for energy system management could lead to cost savings of up to £10bn even if low carbon technologies do not emerge[1]. This saving will be much higher if UK renewable energy targets are achieved.

Building on extensive expert feedback and input, this report describes four smart grid scenarios which consider how the UK’s electricity system might develop to 2050. The scenarios outline how decisions made in policy, regulation, technology, finance, consumer and social behaviour, market design or response might affect the decisions of other actors and limit or allow the availability of future options. The project aims to explore the degree of uncertainty around the current direction of the electricity system and the complex interactions of a whole host of factors that may lead to any one of a wide range of outcomes. Our addition to this discussion will help decision makers to understand the implications of possible actions across other aspects and plan for the future, whilst recognising that it may take any one of a number of forms.

Essential Smart Grid Functions

Given the wide range of possible smart grid functions that can be enabled via various social, technical and organisational innovations the project identified essential functions that any future UK smart grid must possess. Detailed online surveys with over 100 experts emphasised the ability to balance a large share of intermittent renewable generation as the single most important function. Other key functions are closely related. For example, increasing the observability and controllability of networks is directly related to the deployment of demand side response technologies which will enable active management. Active management of networks will facilitate the incorporation of a range of new technologies that can contribute further to decarbonisation – for example, active loads such as EVs and heat pumps.

Scenarios

Each of the four scenarios presented here, developed through a lengthy process of mixed-method engagement with stakeholders, ranging from experts to members of the public, describes the future development of a smart grid. The way in which such a grid may evolve will be highly dependent on a range of interactions between policy, industry, the wider public and others. We present a brief summary of each scenario here, along with key drivers and barriers and implications for policy:

In the Minimum Smart scenario a lack of coordination and long-term vision coincides with weak consumer acceptance of smart technologies and demand side measures. There is, in effect, a lack of strong drivers for

[1] SmartGrid GB (2012) Smart Grid: A Race Worth Winning? London.

any meaningful smart development. Weaker drivers do exist, however, and so there is not a total absence of smartness, although the preponderance of gas generation means there is less of a need for demand side flexibility.

In contrast the Groundswell scenario sees very strong consumer interest in and engagement with the energy system, resulting at least partially from increased national concern over the declining capacity margin and the upward trend in energy prices. This eventually causes a radical paradigm shift, with rapid growth in community and local authority-run electricity generation and even some local network management.

The Smart Power Sector scenario, on the other hand, is defined by consumers highly resistant to changes in the way they use and conceptualise energy. The application of smart technologies can therefore only really take place 'behind the scenes', and this means there are limits to what can be achieved. Policy and regulatory guidance is firm, however, and distribution network operators (DNOs) are incentivised to do what they need to do when, later in the scenario, high numbers of EVs appear and there is significant generation from renewables.

Smart 2050 sets the upper boundary for our scenarios. Well-coordinated and coherent policy action builds strong consumer engagement, resulting in a greater number of smart grid-support services. Engagement differs here from the Groundswell scenario in that it is driven by policy. Strong coordination and the availability of cost-effective options lead to the emergence of a different set of technologies and change the nature of the smart grid correspondingly.

Key messages

Indicators to measure progress. This report demonstrates that diverse outcomes are credible, each with very different consequences for the achievement of government policy goals Examining the impacts of our 'wildcards' reveals that there could be critical 'branching points' that may result in switching between future pathways.

Ensuring equitable outcomes. Smarter energy delivery promises to enable more efficient use of energy infrastructure through the introduction of differentiated tariffs and demand side response programmes. However, our research indicates that the distribution of benefits is unlikely to be uniform within and across different geographical settings. Due to differences in lifestyles, socio-economic characteristics, education levels and normative constraints, consumers' ability and willingness to accept smart technology and services may well vary, even down to a local level. How costs and benefits may best be distributed to prevent the widening of these differences is an area in which further research is required.

Public engagement. The public does appear to understand the lifestyle benefits afforded by various smart technologies, although there is a widespread perception that the risks and/or costs of smart grid implementation will be borne by consumers, whilst the financial benefits will flow to system actors, particularly power companies. This perception of the uneven distribution of costs and benefits is compounded by the widely-felt distrust towards the industry, both of which must be overcome if they are not to act as a hindrance to smart grid development.

Joined-up thinking across smart systems. Both our research and the literature indicate that in order for consumers to share their data there need to be clear and demonstrable benefits. Whilst lower bills may motivate some, others may need to experience benefits beyond financial savings. One way to build consumer buy-in could be via offering integrated services within the energy, transport or healthcare domains. Such an approach may require the establishment of new working relationships and business models across the energy industry and within and between other sectors, such as the information and communications technology (ICT) industry. Expert interviews revealed that the current advisory body, the Smart Grid Forum, is a good starting point, but that more needs to be done; for example, the development of a regulatory architecture that removes and addresses systemic barriers, and the addition of consumer representation in the Forum itself. Further research could be carried out to further the understanding of how smart grids can form the foundations of wider smart systems, such as smart communities and cities.

Risk, Innovation and Investment. Network operators traditionally aim to provide a high-quality service at minimal cost, and there is therefore little scope for innovation. However, the challenges posed by smart grids will necessitate more risk-taking, which will in turn generate learning effects and keep down the costs of finance in future. There must therefore be sufficient incentivisation of such behaviour, supported by cultural changes that encourage innovation at both the network operators and the regulator.

No-regrets technology solutions. The possibility of widely differing future outcomes raises the question of whether there could be some no-regrets technology solutions that might help mitigate uncertainty. For example, the Smart Power Sector scenario shows that balancing the grid would be more difficult when demand side response (DSR) options are not widespread. Bearing in mind the long lead times of infrastructure investments in the power sector, technologies like distributed storage or EV smart charging could be used as a part of a mitigation strategy. Further work needs to be undertaken in this area to identify such technology solutions and develop ways to support their commercialisation.

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List of Abbreviations

CCS	Carbon Capture and Storage
DECC	Department of Energy and Climate Change
DG	Distributed Generation
DNO	Distribution Network Operator
DSM	Demand Side Management
DSO	Distribution System Operator
DSR	Demand Side Response
EU	European Union
EV	Electric Vehicle(s)
ICT	Information and Communications Technology
LCT(s)	Low Carbon Technology(-ies)
Ofgem	The Office of Gas and Electricity Markets
PV	Photovoltaic
TSO	Transmission System Operator
UK	United Kingdom

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Introduction

1

This chapter introduces the concept of 'smart grids', discussing what they are and how they can help the UK to meet its strategic energy goals. We outline the purpose of this report and locate it within the existing literature on energy scenarios, before giving a brief overview of the salient issues that together form the academic and policy backdrop for the project. Finally, we discuss the research methods used to develop the scenarios.

1.1 What are smart grids and what do they offer?

The UK electricity system is expected to include growing volumes of intermittent generation such as wind and solar generation. More generation is expected to occur in homes and businesses and new technologies such as heat pumps and electric vehicles (EVs) may also lead to much higher demand. The way in which networks have operated in the past is unlikely to manage the new stresses these changes will bring in an effective way, and trying to do so is likely to lead to much higher system costs and possibly reductions in the reliability of electrical supply. Smarter energy delivery – often called 'smart grids' as a catch-all term - may include advances such as smarter meters, new kinds of power company, time-of-use tariffs and new technologies for use on the networks. These advances will allow low carbon technologies to be used more effectively, reducing network costs and protecting quality of supply.

Taken together smarter grids are a key enabling technology in efforts to decarbonise the UK's electricity system at least possible cost and while maintaining security of supply. Smart grids can vary widely in nature but are generally understood to include the many technological and non-technological options that may change the way society generates, delivers and consumes energy.

There is currently no widely accepted definition of the term 'smart grid', with definitions varying across working groups and countries [1] . Some commentators consider smart grids in terms of technology alone, some as being purely about innovation on the demand side, while others take a broader view of the potential for smartness in the wider system. All these definitions refer to different functions and capabilities that may be supported by smart grids. This variation reflects the fact that smart grids, as an application, hold together different parts of the system: supply mix; the technology and infrastructure characteristics of the system; data availability, access and type; regulatory and market frameworks; policy incentives and their effectiveness; consumer capability and willingness to engage. As a result of the interactions between of these factors, various functions might be enabled or disabled in different markets. A broad and commonly-used definition comes from the Smart Grids European Technology Platform [2], where smart grids are defined as 'electricity networks that can intelligently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.'

Given the lengthy lead times for investment in energy infrastructure, the multi-decadal lifespan of network assets, and the combined consequences of technological lock-in, learning effects and economies of scale, decisions taken today are likely to impact strongly on the options available to policymakers far into the future.

1.2 Purpose of this report

Using a combination of qualitative and quantitative methods, and drawing on a range of disciplines and stakeholder engagement, this project aimed to:

- Identify key steps likely to determine the future shape of smart grids at the upstream level, together with socio-economic, behavioural, technological and environmental factors influencing the uptake of technologies at the end user level, and
- Develop a range of smart grid scenarios, and subsequently evaluate and refine these through expert and public workshops, with particular attention paid to: through expert and public workshops, with particular attention paid to:
    - critical branching points within each scenario, and
    - spatial differences within the UK energy system.

Scenarios provide a strong tool for organising economic, technological, competitive, political, and societal information into a framework for decision-making [3]. The interdisciplinary nature of smart grids and the interplay of the multiple complex factors that will shape their emergence, make a scenario approach well-suited for analysing and informing smart grid development.

Previous scenarios have highlighted social, economic, policy, and technological drivers of change within the energy sector (see section 1.3). However, little work has been done to examine the roles and priorities of different actors [4], spatial variation (e.g. urban vs. rural, existing energy infrastructure) or behavioural issues. This project incorporates these essential dimensions into scenarios that focus specifically on smart grids. We include stakeholders' assessments of the uncertainties and key dimensions associated with smart grid development.

1.3 Background

We conducted a detailed review of the interdisciplinary smart grid literature; further details can be found in our Literature Review report [5]. There are a number of stakeholder (DECC Carbon Plan [6], National Grid [7], CCC 2008 [8], Smart Grid Forum Scenarios [9]) and academic (Transition Pathways [10], Tyndall [11], Supergen [12], UKERC Energy 2050 [13]) scenarios addressing the transition to a low carbon energy system in the UK. However, the development of smart grids goes beyond the wider energy system, encompassing, for example, policy, regulatory and commercial frameworks, market conditions, and data access and security concerns. The majority of existing scenarios have been developed using optimisation models in order to construct a pathway to a given future goal (i.e. backcasting). Little attention has been paid to behavioural issues other than forcing some constraints in the models.

Our scenarios adopt a system perspective by considering political, regulatory, commercial, financial, behavioural, organisational and technical interdependencies. We pay particular attention to key branching points [10] (where particular events may force or enable switching from one possible smart grid pathway to another, such as public resistance or political change) rather than mere end points from the present day to 2050. A distinctive feature of our scenarios is their 'socio-technical' nature, i.e. their focus on how social and technical systems interact [14]. They explore the future by examining how certain events can influence the range of options available. They do not attempt to quantify the levels of technology penetration in each scenario. The upper and lower limits for each technology are broadly aligned with the most recent public data available from the Smart Grid Forum scenarios [9], generated as part of the Work Stream 3 activities (for a more detailed discussion see Section 5.2).

These scenarios are neither forecasts nor predictions, and are not meant to imply any probabilities regarding the various futures presented. Rather, they are intended to represent plausible and internally-consistent views of the energy system in order to illuminate the many interactions that will shape its development, and so contribute towards mitigating uncertainty about the future. Whilst we identify branching points from one scenario to another, our analysis reveals that certain actions might limit available options in the future.

By signposting key decisions and their implications across the wider socio-technical system, we hope our scenarios will help decision-makers (whether in policy, industry or business) avoid any unintended consequences, given the significant costs and benefits of smart grid technologies and the challenges ahead.

1.4 Research methods

The project followed a 'mixed-method' approach, building on existing literature, but generating new data through extensive stakeholder engagement. The project was carried out in two work packages: 1) data collection and 2) scenario development. Both work packages involved extensive stakeholder engagement (Table 1), via an expert Project Advisory Group, expert interviews, online Policy Delphi surveys (Box 1), an expert workshop and public workshops. Stakeholders included experts in the field of smart grids (and related areas, e.g. consumer behaviour), communities with relevant experience (e.g. electric vehicles, microgeneration), as well as members of the general public.

The Policy Delphi surveys focused on identifying critical technical, social and policy aspects of smart grids. We developed an online survey tool for anonymised collection of opinions of relevant academic, industry, policy and the third sector smart grid experts. The first survey round asked about expected benefits and pitfalls, functions, and barriers, and involved 77 experts (46 male, 31 female). Around half were academics and network operators, with the remainder spanning policymakers, communities with smart grid experience, suppliers/generators, interest groups, consultants and others. The second round expanded on the expected functions of smart grids identified in the first round. The same group of experts was invited to participate; this time 44 (30 male, 14 female) completed the survey.

Finally, public workshops were convened to explore attitudes to smart grids and acceptability of our draft scenarios. Four workshops were convened in a range of locations with diverse samples (see Table 1). In sub-groups of 5-7 people, participants were first asked about their energy use, what appliances and devices they used, and if they thought about their energy consumption at all. The four scenarios were then presented as a typical daily routine of someone living in 2050, and reactions elicited.

Box 1. The Policy Delphi Method

Several projects have used Delphi (or variants, such as Policy Delphi [15]) methods to elicit stakeholder and/or expert views on energy system futures (e.g. EurEnDel; UK Foresight; SuperGen [16, 17]). Not all energy scenarios are developed through Delphi-type techniques but its advantages include the ability to capture a range of expert (and potentially non-expert) views on a topic where the field is young (with little published literature), rapidly developing, controversial and/or where long-range predictions are required.

The Policy Delphi approach uses an iterative method in which there are several (usually two or three) 'rounds' of consultation, and participants are typically shown the results from the previous round to respond to (often by providing a revised response) and potentially reach a consensus. Data is collected anonymously so that participants can provide their views in an uninhibited fashion and are not tempted to follow the opinion of established figures in their area; eliminating stakeholder bias.

Table 1. Research and stakeholder engagement methods

Method	Sample Size	Timing	Participants	Aims	Report Section
Policy Advisory Group	12	Every 6 Months	Experts involved in smart grids (Ofgem, National Grid, DNOs, suppliers, technology companies, NGOs, academics).	To guide project on key smart grid issues, data collection and scenario development.	n/a
Expert Interviews	18	Feb-Mar 2012	Experts involved in smart grids and related issues (the UK Government, Ofgem, National Grid, DNOs, consultants, trade associations and NGOs).	To reveal as much of the landscape as possible to ensure no key element was omitted from the Policy Delphi expert survey.	2.1
Policy Delphi (Online Surveys)	Round 1: 77	Apr 2012	21 academics, 12 network operators, 6 consultants, 5 interest groups, 5 suppliers, 3 communities with SG experience, 3 policy-makers, 1 generator, 1 regulator, and 7 'other' (13 no response).	To identify critical technical, social and policy aspects of smart grids via a two-stage anonymous online survey tool.	2.2
	Round 2: 44	Sep 2012	11 academics, 11 network operators, 4 suppliers, 2 interest groups, 1 regulator, 1 generator, 1 policy-maker, and 13 'other'.		
Expert Workshop	20	May 2013	Academic, industry, policy and third sector smart grid experts.	To feedback on draft scenarios and pathways.	2.3
Public Workshop	53	Sep-Oct 2013	Four locations: two urban (Cardiff, Brixton) and two rural (Fintry, Mere Green); two with smart grid-related experience (e.g. microgeneration) and two without. 51% male; range of age groups, education levels and household characteristics[i].	To explore public attitudes to smart grid issues and responses to draft scenarios via structured participatory exercises.	4.1

[i] Range of household and home types: 20.8% single-adult households, 52.8% live with one other adult. 62.3% do not have children at home. 49% semi-detached or detached house, 20.8% flat. Mean home 62 years. 86.8% have internet at home. 41.5% own their house outright, with most of the remainder having a mortgage.

Research Findings

2

This chapter presents the research findings from a series of in-depth interviews and a policy Delphi, and introduces the methodology employed for the construction of a small number of sociotechnical scenarios.

2.1 Smart grid landscape

This section describes the findings from the expert interviews, designed in order to identify the main themes to be explored and incorporated into the scenarios.

Predictability and uncertainty

The problem of predictability arose in a significant number of interviews, most commonly in regard to distribution networks, issues arising from the replacement of RPI-X[ii] with RIIO[iii], and the uncertain needs of the electricity system. Many stakeholders felt uncertainty over how the potentially significant expansion of new energy technologies will shape the network and make it difficult to make definitive assessments, even over the next decade (relating directly to the 2015-2023 operating period of RIIO-ED1). No-one felt able to properly evaluate network needs or possible evolution beyond 2025, making it challenging to outline scenarios beyond 2030. This throws up the question of how regulation would need to evolve alongside developing technology and market services. Experience suggests that this would have to take into account the changing circumstances on an ongoing basis.

There is also considerable uncertainty in the medium to longer term:

- How do we move to more sophisticated systems and who pays for those?
- What will the demands on the system be after 2020, and how do we stay ahead of and fulfil these system demands?
- How will regulation evolve with technology and market services?
- How to give signals which allow flexibility beyond the end of the 2023 distribution price control review and provide sufficient information to allow DNOs to make decisions about post-2023 investment?
- Might a flexibility mechanism/review mechanism in RIIO-ED1 be a necessity once we have more information about how things work in practice?

The results of most Low Carbon Networks Fund[iv] projects will not be available until after RIIO-ED1 starts, so there will be limited data about feasibility to inform its introduction. It is possible some benefits of RIIO might only really become apparent in practice, but so might the pitfalls.

Planning and investment by DNOs

Stakeholders agreed that previous assumptions about the network no longer held true and DNOs would have to respond differently. The change to the regulatory system for DNOs creates a new operational environment; DNOs will have a far more complex task and require more interaction than has been the case.

Since their privatisation, DNOs have tended to be conservative, low-risk and low-return. R&D investment fell dramatically as a result of regulatory incentives to minimise costs. DNOs will need to take more risks in adapting to the new realities of the system. More innovation will be required, adding considerably to costs, and requiring a bigger return. Risk management will become a key element of their overall management strategy and it is possible some will respond less capably to these challenges.

DNOs will need to trade off primary assets (e.g. wires) against more advanced control and it is likely that the balance of this trade-off will change over time, with important

[ii] Retail Price Index, excluding mortgage interest payments
[iii] Revenue = Incentives + Innovation + Outputs: A performance based model for setting the network companies' price controls by the regulator Ofgem
[iv] Ofgem set up the Low Carbon Networks (LCN) Fund as part of the electricity distribution price control that runs until 31 March 2015. The LCN Fund allows up to £500m to support projects sponsored by the Distribution Network Operators (DNOs) to try out new technology, operating and commercial arrangements.

implications for effective regulation. The level of risk that Ofgem will tolerate will also be significant in future distribution price control reviews. There is potential conflict between Ofgem's perspective on allowable risk and the direction the DNOs (and transmission networks) want to take, either collectively or individually. This may constrain innovation.

Linked to this is the issue of whether Ofgem would allow investment ahead of need, and if so, to what extent. A conservative response from Ofgem could decelerate innovation and limit appetite for risk. It was generally agreed that Ofgem would prefer to see third parties involved in innovation on distribution networks, partnering with DNOs. While this has value in terms of offsetting risk it might also mean a complex double sales process with no guarantee of return.

Another issue for stakeholders was when development should begin - in 2015, 2023 or somewhere in between? There are some key low carbon technologies which will present serious challenges for the current electricity system. Rapid expansion of even one of these could require significant changes. Effective system operation will depend on how fast DNOs can respond. Thus, a key question regarding investment and smart grid development was whether to include smarter technology ahead of the curve or go slowly to reduce costs and try to react quickly to sudden change (e.g. EV uptake). Given the new DNO incentives, much will depend on how they respond in terms of forward planning.

At the time of writing, six DNOs have been considered for fast-tracking under RIIO-ED1 with only one being successful. Since fast-tracking was seen as an attractive incentive by the experts we interviewed, this may reflect problems for DNOs in understanding what would be required from them. Submissions by the six DNOs also included proposed innovation strategies. However, four failed to satisfy Ofgem's minimum requirements and only one made a success case for funding above the default level of 0.5% for its Network Innovation Allowance.

Supply sector

Suppliers' concerns were more focussed on the impact of increased transmission and distribution costs on bills. They were less worried about demand management as long as power stays on. This is significant, since suppliers have the potential to take a leading role in addressing demand amongst consumers, due to their relationship with the consumer.

Coordination

One fairly common concern was a perceived lack of vision in planning for smarter energy delivery beyond 2020, and a desire for more coordination was often expressed. Many stakeholders thought the Smart Grid Forum was a step in the right direction but that more coordination would be needed, with the Department of Energy and Climate Change (DECC) singled out as needing to provide a coherent lead.

Local grid issues

In the past, assumptions about technologies such as EVs and heat pumps were that they would be evenly distributed, but DNOs now think high concentrations in specific area is more likely (e.g. EVs in London or ground-source heat pumps in areas off the gas grid). This will require development of smart grids on a 'hotspot' basis, with multiple implications. Where clustering occurs in areas with little system headroom there is greater likelihood of problems. The lack of information which DNOs currently have on rural networks and the lack of flexibility inherent in them may need more work to justify the precise scale of the problem. 'Hotspot' development will mean variable levels of smartness across energy networks; thus the degree of smartness may vary strongly on a geographical basis.

Smart meter rollout

A substantial number of stakeholders were concerned about the limits of the smart meter rollout planned for 2016-19 and its enabling communications system. Many outlined the problems of the supplier-led smart meter roll out and the conflicting supplier priority of minimising costs and the DNO desire to enhance functionality.

Views differed as to when and how smart meters, which go beyond the 'smartness' of the initial roll out models, would be needed. This will depend both on the smartness of the typical meter installed and the rapidity with which their limits are reached. It is unclear whether demand for particular data will lead to any upgrading as a result of the broken value chain. The move to more advanced meters may eventually be limited by the longevity of the initially rolled out meters.

There was concern over the quality of the communications system being introduced to gather data from smart meters. Some stakeholders felt that DECC's budgeting would mean severe limits on bandwidth, meaning little potential to expand beyond simple meter reading, regardless of the functionality of the meters. Many felt a second generation communication system might have to be introduced relatively quickly.

Consumer engagement

There was considerable uncertainty about the level of consumer engagement that will emerge, and industry stakeholders (e.g. DNOs) seem unlikely to act on data estimating levels of engagement unless it comes with a high degree of certainty (e.g. from real world data). Non-engagement may limit the options available to DNOs, new entrants to the UK electricity supply industry, such as Distribution System Operators (DSOs), and for overall system balancing.

Issues such as access to data, time-of-use tariffs, smart-enabled domestic goods and willingness to shift energy usage will impact substantially on the ability of other stakeholders to provide new services and apply new methods to system management. This presents a potential 'chicken-and-egg' scenario, which could limit uptake of more advanced consumer-related services unless action is taken to open up markets.

Skills shortages

Several stakeholders mentioned a skills shortfall amongst power companies. There was doubt as to whether human resources departments were ready to respond to the changing situation regarding their organisations' skills. Power electronics and telecommunication skills were cited as necessities, alongside modelling expertise for DNOs. Concern was also expressed that DNOs may have sufficient skills to handle Low Carbon Networks Fund projects but not to roll out knowledge gained more widely.

2.2 Smart grid drivers, barriers and functionalities

Building on the expert interviews, our two-stage Policy Delphi online survey explored in more detail smart grid benefits, pitfalls, drivers, barriers and functionalities as elucidated by experts and stakeholders. Findings from the Policy Delphi survey are summarised in this section.
Benefits and pitfalls of smart grids
Broadly, experts agreed on the need to make electrical delivery smarter, and that smart grids can afford various benefits. Cost reductions were the most cited expected benefit, while investment risk was the most cited pitfall of smart grids (Box 2). Experts expect that smart grids will deliver significant cost reductions for the grid, via deferred investment, efficiency savings, or otherwise, provided that the costs of implementation and maintenance of the required technologies can be met.

Yet not all the solutions involved in making the grid smarter were viewed favourably, with a measurable proportion of experts finding them unproven, underdeveloped, complex and difficult to implement. The expected benefits of a functional smart grid involve facilitation of renewable energy, better network balancing, and emissions reduction – all of which are high on government energy and climate agendas. However, customer protection (e.g. against price rises) was not generally seen as an important functionality. Rather, economic and technical benefits seemed to be prioritised over social ones.

Box 2. Expert opinion on the benefits and pitfalls of smart grids (open-ended survey question)

The top-cited expected benefits from smart grids were (% of experts):

- Cost reduction in different levels of the system (39%)
- Improved efficiency in generation, delivery and use of assets (39%)
- Facilitation of renewable energy sources of electricity (24%)
- Emissions reductions (24%)

The top-cited expected pitfalls of smart grids were (% of experts):

- Costs or lacking/risky investment (42%)
- Disengaged or uncooperative customers (27%)
- Complexity or difficult-to-manage solutions (21%)
- Data protection/privacy concerns (18%)

At the same time, consumer engagement, community involvement, the potential for demand management but also potential resistance to it, were also identified as both potential benefits and pitfalls. Data protection and privacy was clearly identified as a problematic aspect inherent to smart grids, demanding greater transparency and data protection safeguards to gain customer trust.

Drivers and barriers of smart grids

We explored drivers and barriers to smart grids within the following areas:

Standards and technical issues. Smart metering and communications are paramount here; more specifically, the need for standardisation of metering functionality, communication protocols and technologies to drive a smarter grid, as well as effective device rollout. Other issues deemed crucial for smart grids include active network monitoring, the method and timing of devices' communication with each other and with the network, and particularly the way data is shared and stored. In addition there was an array of lower-priority issues such as the capacity of networks to support EVs.

Data handling. Data protection, security, and privacy guarantees emerged as the key issues here. Concerns around cyber security, the willingness of companies to share data with each other and with the network, and then the security of this data once collected and/or shared are all likely to have a substantial impact on customer trust and cooperation. Other issues raised included the minimum level of transparency to make data useful to companies, and the limits of what energy providers may be able to do with this data.

Market structure, regulation, and coordination between DECC and Ofgem. In contrast to the technical areas above, there was less agreement here on the priority drivers/barriers, exposing a broad spectrum of policy and regulatory topics. One recurrent theme was fragmentation of the energy system and markets; with players at many levels either having conflicting interests or lacking clearly defined responsibilities, resulting in inertia in the system and calls for restructure. Another recurrent theme was consistency and coordination between market players and in policy and regulation, so that clear and consistent messages (including a long-term vision and commitment to change) are communicated to the market.

Customer engagement. This area included the clear communication of potential smart grid benefits to consumers and the understanding of consumer responses to smart grid capabilities (e.g. shifting consumption to off-peak) and associated changes (e.g. pricing, customer-tailored solutions).

Investment. Risk aversion was seen as the most important barrier and the most important pitfall (Box 2). Uncertainty of return on investment and about government commitment and regulation are a financially unattractive combination; this limits willingness to fund any changes on the grid, for fear that broader changes may not be implemented, or that implementation may not last long enough for investments to return profits.

Functions of smart grids

Next, we examined potential and expected functions of smart grids and whether these were essential, desirable or not important. From a list of 20 potential functions of smart grids, identified from previous research, and to which experts could add further functions, five were chosen as essential by over 70% of experts (Table 2) and were not voted 'not important' by any respondents. Few significant differences by background or gender were found (although 'To protect vulnerable consumers from price increases', was seen as essential more by social scientists and engineers than by business or 'other' sector respondents).

We then examined the interdependency and spatial aspects (i.e. critical prerequisite steps and geographical differences) of these top five functions, along with energy storage (the most popular 'other' option freely proposed by the survey participants). Given its potential for reducing the need for any of the other functions of a smart grid, energy storage may also be identified as a potential branching point for smart grid development.

With the exception of function 2, where the installation of monitoring and control equipment was clearly prioritised, followed by smart meters (for monitoring and perhaps control at a domestic level) there was generally a wide spread of opinions on what constitutes prerequisite steps for each function. These included addressing generation forecasting and DSR for function 1, smart meter installation and customer acceptance (function 3), installing monitoring, metering and control technology, and resolving responsibilities among energy market players (function 4).

Of the six functions, four were expected to be implemented either through trials gradually being connected to the grid, or in parts of the network that are in critical need. In contrast, function 3 (deployment of demand side technologies) was primarily expected to be implemented by rollout, with local trials as a second option; and function 5 (integration of active loads) was equally expected to occur via local trials to be connected gradually, and on an ad hoc basis.

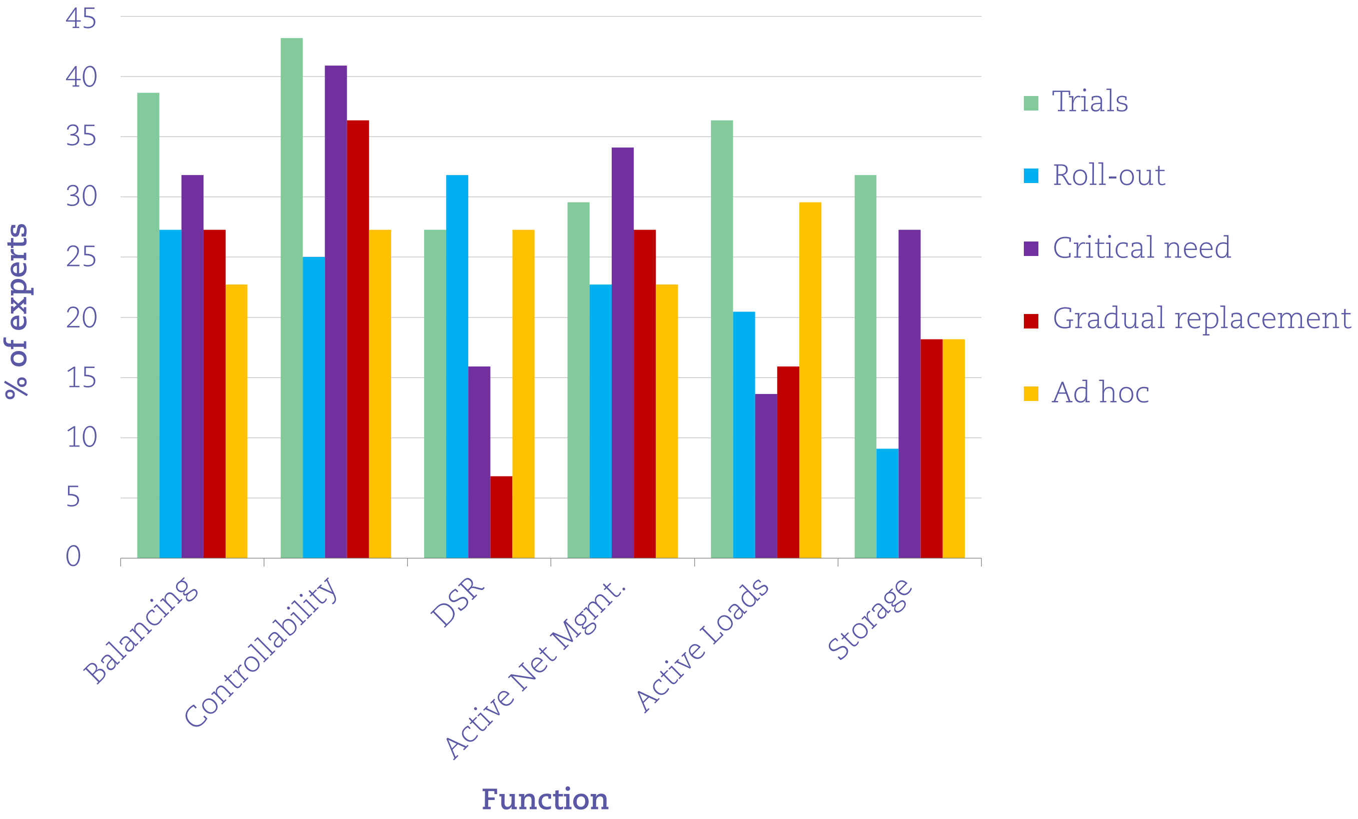
In terms of likelihood of implementation, all functions were judged as likely to be implemented, albeit to a low or moderate extent (Figure 2).

Table 2. Essential smart grid functions

Function	% of experts rating 'essential'
1. To balance a power grid with a large share of intermittent renewable generation	82
2. To increase observability and controllability of the power grid	75
3. To enable deployment of demand side response technologies	74
4. To enable active network management	73
5. To allow integration of active loads (e.g. electric vehicles, heat pumps)	71
6. To facilitate energy storage*	12

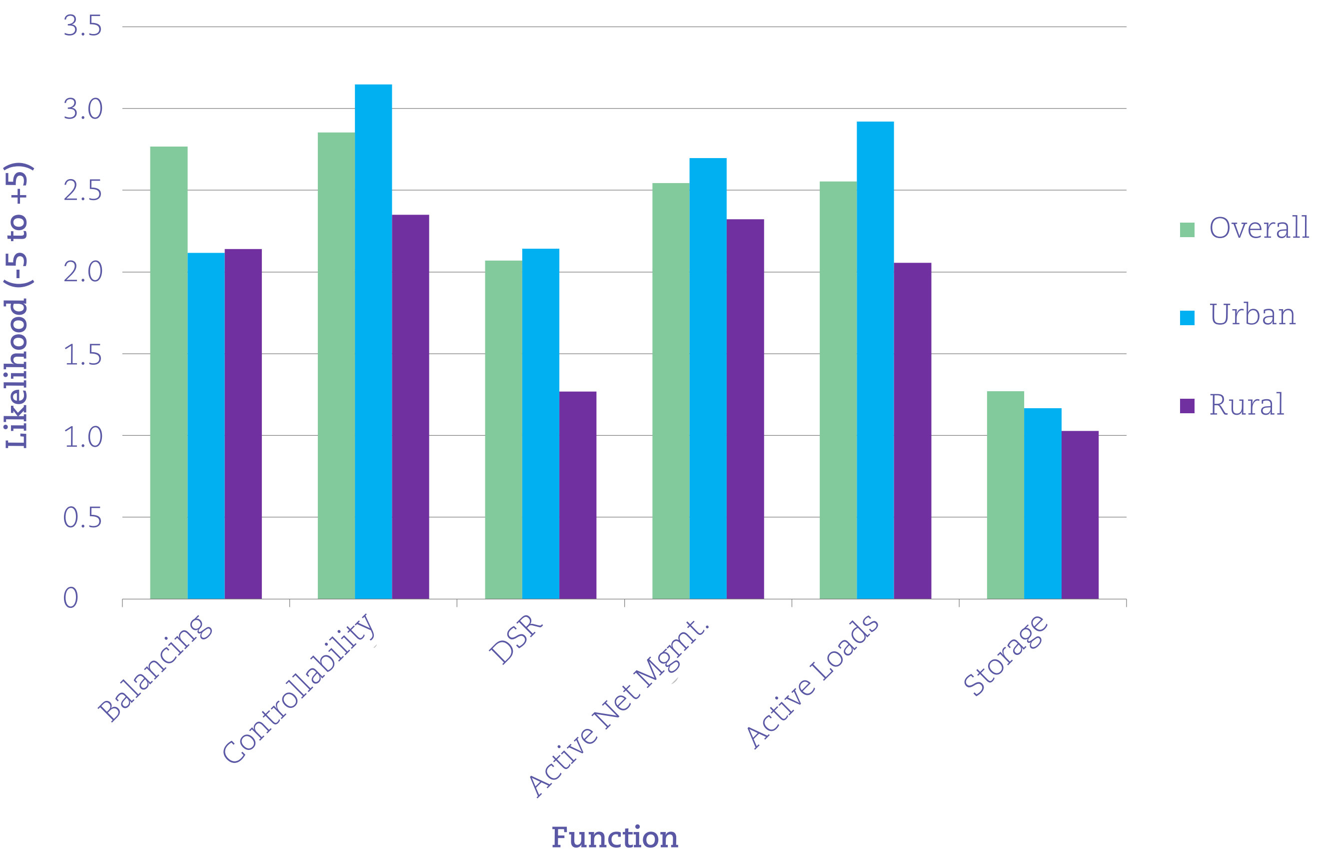
* This was the most popular unprompted function offered freely by the survey participants

Figure 1. Expected method of implementing each function*



* Note that experts could select more than one method.

Figure 2. Expected likelihood of implementing each function in different geographical contexts



There was no negative expectation for any of the functions, reinforcing their perceived importance. The most likely functions expected to be implemented were observability and controllability of the grid (function 2), followed by integration of active loads (function 5). Facilitating energy storage (function 6) received the lowest likelihood ratings, perhaps reflecting our assumption of storage being a branching point in smart grid development.

In terms of spatial variation, there was an expectation that virtually all functions would be more likely to be implemented in urban settings than in rural ones; this was particularly the case for DSR technologies, active load management, and controllability (Figure 2).

2.3 Scenario pathways and their plausibility

We used the Field Anomaly Relaxation (FAR) method of scenario development [18] (Box 3).

Analysing the subject area we identified key dimensions (or 'sectors') such as government policy, and three or four alternatives futures within each sectors (known as 'factors'). In the case of government policy, for example, these may be strong or weak policy support for low carbon technologies (LCTs). The seven sectors are listed below (see Figure 3 for full descriptions):

The key variables identified, as in Figure 3, were laid out in a 7x4 sector/factor array, titled MUDSPIN, after the first letter of each sector. The co-existence of each factor in a sector was checked against another one across the other sectors by assigning a consistency rating between -3 and 3. Consistency ratings were discussed and agreed upon by pairs of project team members and reviewed by the team as a whole.

The Parmenides software package was used to calculate consistency rating of each combination (made up of average pairwise ratings) and to rank the most consistent combinations. These were then checked for contradictions, and empirical and normative constraints. The surviving combinations were grouped together to form similar clusters which could conceivably move from one combination to another – the most subjective element of the process – which were in turn then ordered into an intuitive sequence of 'can I see this world leading to that one?' [18].

This process resulted in a sequence of events, branching out into the future in a tree-like diagram (Figure 4), to which we then applied the earlier findings to give richer detail. By assessing and evaluating different combinations, these pathways were developed into four scenarios.

The plausibility of different pathways for each scenario and their coherence and timescales were discussed at the expert workshop, revealing a range of issues and considerable divergence of opinion (especially in relation to new technologies and associated measures). We outline findings that had the most impact upon subsequent scenario development.

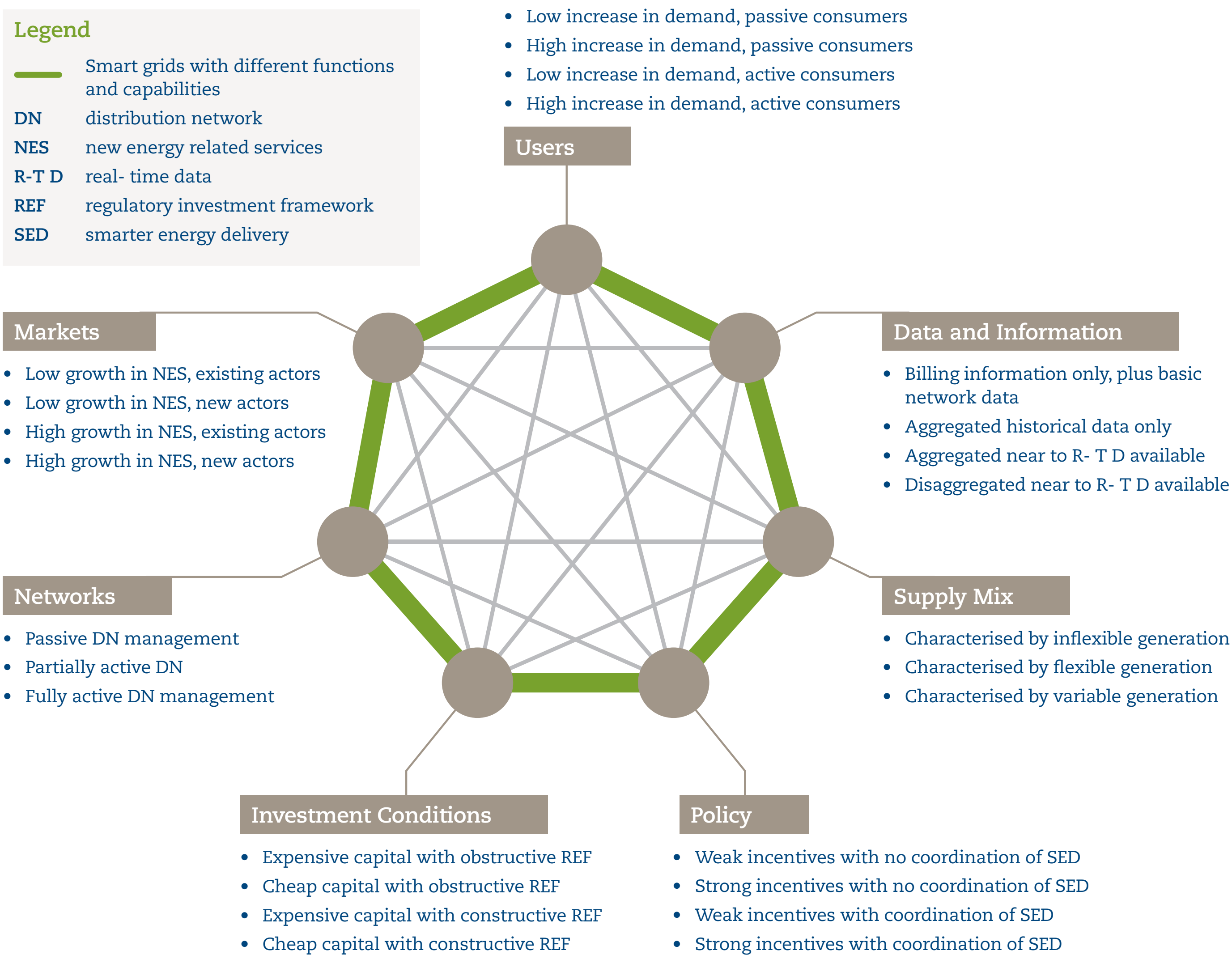
Policy and Regulation: There was a strong feeling amongst participants that RIIO and Electricity Market Reform would be central to many of the initiatives that would determine the overall smartness of future energy delivery

Box 3. The Field Anomaly Relaxation (FAR) Method

This approach is highly structured and transparent and, unlike many scenario development exercises, does not constrain outcomes to a certain number of scenarios. FAR is able to take into account many more factors than a twin-axis framework and analyse their combinations systematically to gain insight into how the pathways branch out into the future.

Figure 3. Smart grid scenario key variables

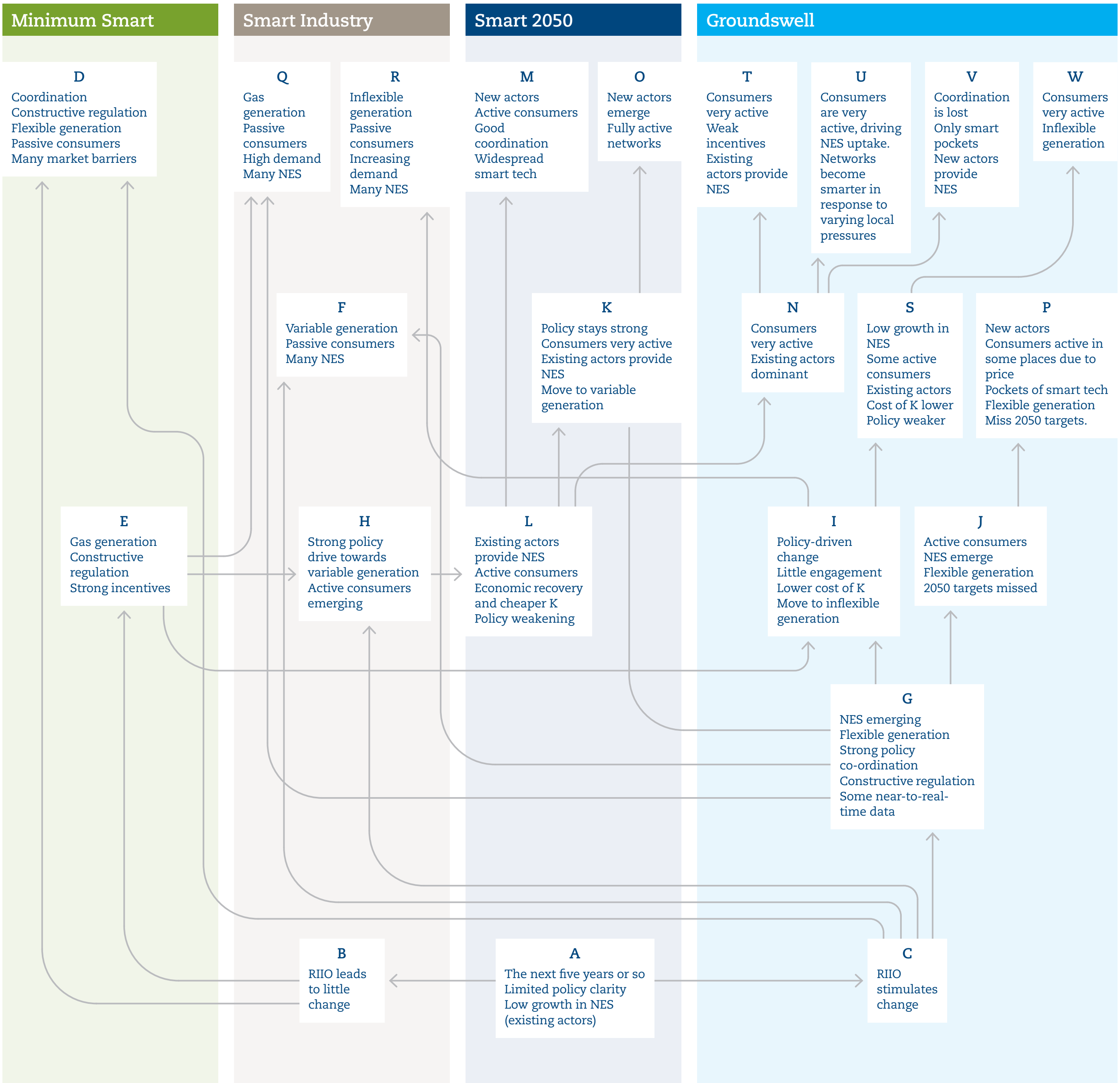
Markets	The extent to which new energy services emerge
Users	Both the overall level of demand and its flexibility
Data & Information	The availability of data from smart meters and substations
Supply Mix	The defining characteristics of the power generation system
Policy	The strength of government support for low carbon technologies
Investment Conditions	The investment and regulatory context
Networks	The extent of smart technology implementation by networks



– in the short term at least. In the longer term, network smartness is likely to be driven by the generation mix, and therefore policy measures designed to encourage or discourage certain types of generation will have significant impact on the way in networks will develop over the coming decades.

Given the central focus of RIIO and EMR, government uncertainty is seen as being, by far, the greatest risk and the most substantial barrier. Government actions are therefore a driver and a barrier to smart grid development. As the government has many, often competing, objectives and concerns, other than environmental ones, that may have an impact on network smartness.

Figure 4. The Faustian Tree



NES New Energy Services
K Capital

For example, if supply security drives greater gas generation, then supply side flexibility may negate much of the need for advanced DSR technologies (though there may still be system and cost benefits from having some DSR). Further, since policy is formulated and implemented at a national level, incentives for DNOs to act in certain ways are likely to lead to a degree of uniformity (or similarity) in DNO behaviour. Similarly, local/community or regional communications infrastructure is unlikely to develop in place of a system co-ordinated at a national level. However, this is not to say that subnational actors do not have a role to play: it was felt in some cases that local authority involvement in the energy system could affect network development.

RIIO: Many participants recognised that RIIO failing to achieve any meaningful change is a possible outcome. Some highlighted the 'cliff-edge' for commercial actors trying to attract new customers; because regulation starts once they have more than a certain number, there is an incentive either to remain small or become very big very quickly. There was also discussion around how the outcome of RIIO should be regarded. Participants agreed that it should not be seen simply as smart vs. not-smart – instead the question is whether RIIO provides enough of a stimulus to sufficiently incentivise DNOs to seek out new behaviours, leading to three plausible outcomes: RIIO stimulates change as intended, less than intended, or not at all.

Technological: The effectiveness of policy measures designed to encourage or discourage certain types of generation were perceived as having a significant impact on how networks will develop (see Policy/Regulatory above). Different conceptions of 'smartness' were also raised. In keeping with our Smart Power Sector scenario, the first is a high level of 'smartness' on the generation and supply side (e.g. including storage and large amounts of interconnection to mainland Europe) and sees smart metering succeeding in engaging consumers in greater numbers (see Consumers, below). Such a system may be very smart on the generation side in rural areas (with advanced monitoring and control systems) but less smart in consumption, which may, for example, be restricted to key technologies such as EVs rather than widespread adoption of DSR-relevant products in customers' homes. There was an extremely wide range of opinions on when certain technologies may be introduced. Estimates placed the emergence of both grid-scale storage and the advent of residential real-time pricing over a twenty year timeframe. This is consistent with psychological research on difficulties conceptualising the future [19].

Finance: There was some observation that the cost of capital could be largely irrelevant for any scenario. There is currently cheap capital available but very little investment, due to regulatory and policy uncertainty. Additionally, DNOs are currently able to access debt at low cost because they are low risk. Requiring them to take on more risk (as expected via the changes in pricing mechanisms, i.e. RIIO) may adversely affect their risk profiles from the point of view of investors, thus increasing the costs of financing any smart investments.

Consumers: There was a very strong concern, regularly expressed, that consumers will be unlikely to play a very active role in the development of smart grids until quite a late stage in the scenarios. It was felt that regulation, rather than pressure from consumers, would drive the behaviour of DNOs. However, it was suggested that if consumers do become active, they are unlikely to return to passivity. There were questions around the description of consumers becoming 'active'; this might be better expressed by asking what types of services they will use. A radical alternative to this conception of the consumer's role is that of a 'consumer-only' smart system, in which there is less smart generation and supply but end users, predominantly in urban areas (and not only in the domestic sector), have become smarter in how they use energy. Despite the generally-anticipated lack of consumer involvement, it was the view of most participants that more advanced smart meters will achieve significant penetration around 2025 as the old ones will need replacing. This will be a market, rather than a policy decision, so will happen regardless.

Markets: There was a general view expressed by one group that entrepreneurial activity

Box 4. Active and passive networks

Active and passive networks. 'Passive' distribution networks mostly have power only flowing to the consumer. 'Active' networks may have micro, small or medium scale generators, and residential customers with higher loads (e.g. an EV). Active networks need real-time monitoring and management, but offer opportunities for an increased range of services to consumers. They may offer improved operational security through increased levels of automation.

is likely to occur in niches and that how this is managed or encouraged, and how new techniques emerge into wider use, is a question for competition policy as well as regulation. A particular concern was raised that despite being incentivised by the network innovation programmes to trial new technologies, DNOs might lack the incentives (or the skills) to roll out these technologies further. New companies may expand and remain independent, or they may be bought up by dominant players and either nurtured or stifled. The latter might affect transition to greater smartness by limiting the competition in the market. This progress could well depend on the degree to which incumbents choose to adopt and explore new technologies.

Scenarios: With regard to specific feedback for the scenarios presented to the group, it was suggested that Smart Power Sector and Smart 2050 might in fact be very similar up until roughly the year 2030, after which they would diverge due to the absence of consumer engagement. Some felt the regulator is unlikely to act unless levels of EVs, heat pumps and renewables become significant, because very smart networks simply won't be needed otherwise. It was felt that 'partially' active networks therefore serve no purpose.

Prior to the workshop our Minimum Smart scenario had contained high volumes of nuclear generation towards 2050. Experts felt this would in fact drive more smart and ancillary services and so looks out of place in 2050. It has therefore been removed, although it was recognised that it is possible for more nuclear to appear later than 2050, and that if this were the case, nuclear adoption could act as a branching point. For example, new reactor designs and additional smart services would mean that we might as well continue down that pathway. It was also noted that a pathway characterised by inflexible generation is less plausible as by the time nuclear power plants are built there would be a similar amount of variable generation. Finally, there was agreement that more work was needed on the market structure dimension within the Groundswell scenario; in particular, closer examination of how the broken value chain might be addressed in order to encourage better and more rapid innovation, which is highly unlikely to occur without an adequate profit motive, and is a direct consequence of the lack of competition within the market.

Box 5. Ancillary services

A range of services necessary to the efficient running of the electricity system that are outside the basic needs of generating and delivering power. Some of these (such as regulation and reactive power) are required during normal operations to maintain the necessary balance between generation and load in real time and maintain voltages within the required ranges. Other ancillary services (such as contingency reserves) provide insurance against minor problems becoming catastrophes. Finally, black start services are required to restore the bulk-power system to normal operations after a major outage.

Smart Grid Scenarios

3

This chapter presents the scenarios in narrative form, as they were developed following a lengthy data collection process. Each of the four scenarios is described in detail, followed by discussion of how it is possible to move between scenarios, and the impact of wildcards.

In Figure 4, each scenario building block corresponds to a combination of MUDSPIN sector/factor array choices. Scenario narratives were developed in order to describe the most influential characteristics, those that define the progression along the pathway, and these were set to a chronology following the expert workshop. As already noted, the scenarios outlined are not forecasts, but illustrate plausible future energy system pathways and the interactions that are likely to shape their development.

Figure 5 summarises the key steps across the four scenarios. In the Minimum Smart scenario a lack of coordination and long-term vision coincides with weak consumer buy-in and results in the need to purchase carbon credits to meet environmental targets. The level and scope of smartness for this scenario are therefore low.

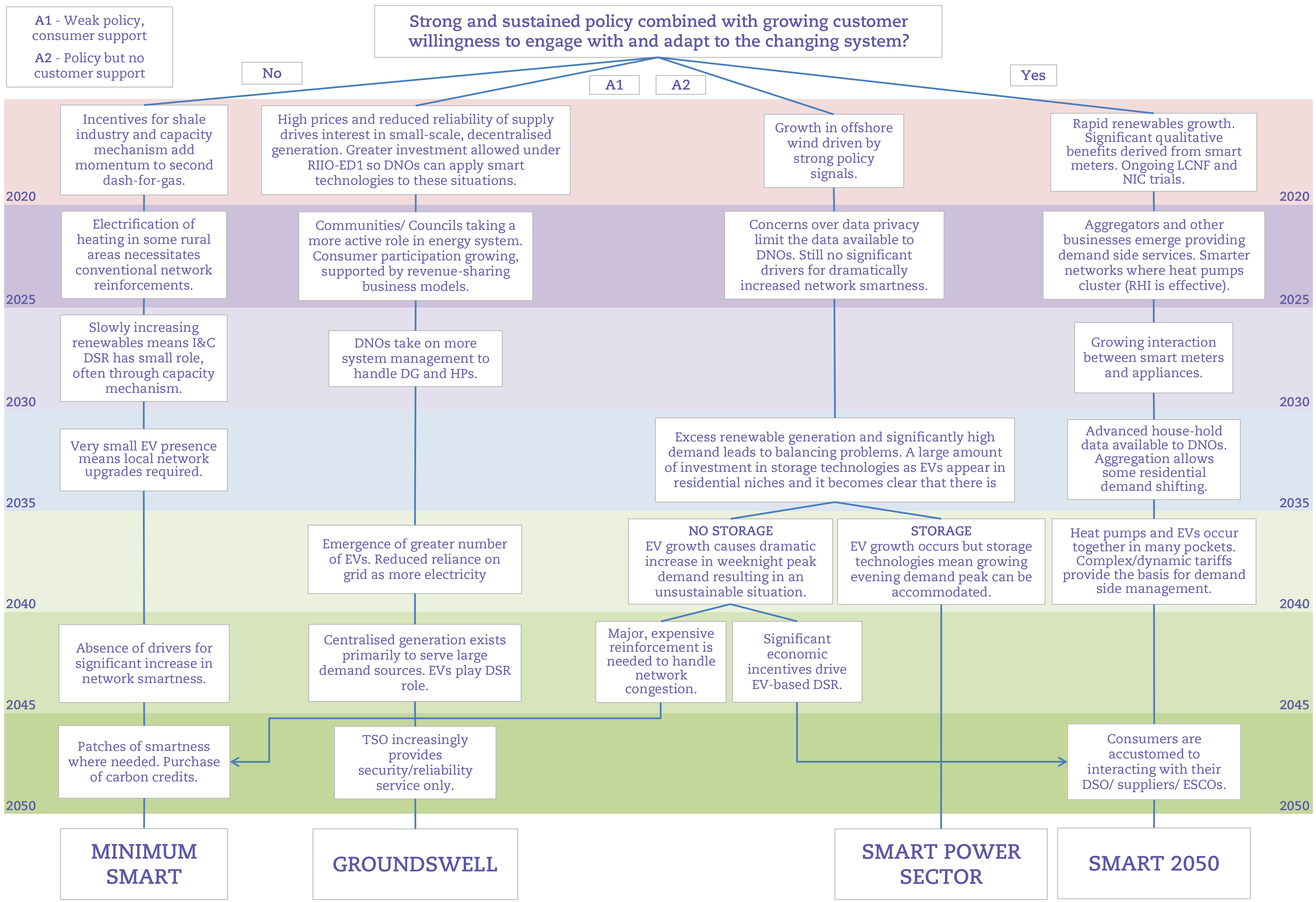
The Groundswell scenario, in contrast, sees strong consumer interest in and engagement with the energy system, resulting at least partially from increased national concern over the declining capacity margin and the upward trend in energy prices. This causes a radical paradigm shift at a community and local authority level, leading some areas to generate their own electricity and sometimes even manage their networks.

The Smart Power Sector scenario features highly resistant consumers. Smart grid developments therefore take place 'behind the scenes', although this means there are limits to what can be achieved. DNOs are, however, incentivised to do what they need to do in order to deal (much later on) with the emergence of EVs. There is a greater role for interconnection with Europe and grid-scale storage.

Smart 2050 sets the upper boundary for our scenarios. Well-coordinated and coherent policy action builds strong consumer engagement, resulting in a greater number of smart grid-support services. Engagement differs here from the Groundswell scenario in that it is driven by policy and the availability of desirable options, leading to the emergence of a different set of technologies and changing the nature of the smart grid correspondingly.

The scenarios are discussed in detail in the next sections in decadal timespans across broad categories of Supply, Demand and Networks.

Figure 5. Key scenario steps



3.1 Minimum Smart

Defining characteristics:

- A substantial amount of flexible generation results in a reduced need for smart technologies.
- Consumers remain mostly passive and not interested in adopting DSM.
- Network smartening only occurs as and when it is required or equipment is replaced.
- Substantial barriers remain, both to market reform and new market entrants.
- International permits and interconnectors are used to meet climate targets.
- Energy prices continue to rise.

Now – 2020

Supply Side

The UK's fitful economic recovery means environmental objectives are low on the political agenda and the priority remains the restoration of growth. There is continued pressure on DECC from industry and the government to reduce financial support for green policies. The Treasury offers tax breaks to the shale gas industry and introduces policies that conflict with DECC's long-term carbon reduction objectives. At the end of the decade a number of coal power stations shut due to the Large Combustion Plant Directive, most nuclear stations are reaching the end of their working lives, and the share of gas in the UK generation mix increases steadily, aided by the capacity mechanism. Although wind generation continues to grow there is little willingness to adopt more ambitious policy measures in this area. The strike prices established under the Contract for Difference for low carbon generation act as a price guarantee for the nuclear industry, with the government willing to amend this in line with perceived need. In the middle of the decade construction begins on new plants.

Demand Side

Smart meters are installed in homes and small businesses. Although capable of more, they are used only for the relaying of billing information. The accompanying in-home displays show energy consumption in financial terms but consumers are not engaging well, in part because trust in energy suppliers remains low. Consumer energy consumption patterns show no sign of changing and there appears to be little appetite for what bill payers regard as quite intrusive DSR technologies, such as devices that suggest alternative times to run appliances. Due to an installation process of varying quality, including problems in billing systems and an inadequate public information campaign, public support for the process is lukewarm. This slows down the rollout and the number of meters installed by 2020 is lower than originally anticipated. Energy prices continue to rise as political momentum towards a gas-centred system gathers pace, but public antipathy towards onshore renewables and other green policies remains sizeable.

Networks

Despite weak policy and regulatory guidance smart technologies are developing and being put to use. DNOs, motivated by cost savings, install smart monitoring equipment at medium voltage substations, as and when it is necessary, but in the absence of significant increases in demand levels DNO innovation remains low. The eight-year time span of RIIO-ED1 does little to drive innovation; DNOs are not motivated by the need for substantial innovation in the early part of the RIIO-ED1 period up to 2020 as they are uncertain of the extent to which enhanced smartness will be needed within the 2020-2023 period. Further, much of the requirement for connection to networks in the RIIO-ED1 period can be met with existing capacity – current system headroom is sufficient in many cases. In the absence of a clear pathway for carrying over the value of investment in innovation from ED1 to ED2, DNOs wait for RIIO-ED2 to begin before enacting cost-saving measures so that they can receive the maximum financial benefit from doing so. DNOs continue to engage with the Low Carbon Networks Fund, then the Network Innovation Competitions and the Network Innovation Allowance. A basic communication infrastructure is put in place alongside the national smart meter rollout and the Data and Communications

Company, Data Services Providers and Communications Service Providers begin to operate. However, the functionality of the system is limited to automated meter reading.

As of 2013, National Grid have already been working with DECC and Ofgem towards a stated goal of devising possible additional safeguards to try to address some of the risks which might threaten system security in the near term. Two possible new balancing services have been suggested: Demand Side Balancing Reserve and Supplemental Balancing Reserve [20,21]. The primary goal is to give National Grid more options in the case of narrowing capacity margins, particularly in 2013/14 and 2014/15. Demand Side Balancing Reserve is also intended to lay down regulations which will be conducive to the possible growth in demand side services within the developing context of the Electricity Market Reform.

2020 – 2030

Supply Side

The UK fails to meet its 2020 renewable energy targets as the policy focus has been on securing supply through increased gas generation. The public stance towards onshore wind farms and other renewable technologies, such as large-scale photovoltaics (PV), remains lukewarm as consumers associate rising electricity prices with environmental policies. Increases in offshore wind energy continue to prove tough to finance at the scale needed to hit the 2020 targets and the sources of capital needed prefer to look to onshore wind development and other renewable energy sources outside the UK. Offshore wind does continue to expand below the levels of the targets and by the mid-2020s the energy system incorporates around 15GW. Policy encouraging the construction and operation of gas-fired power stations over the previous decade and support for the exploration and exploitation of UK reserves spurs on the development of the shale industry. This offers a modest improvement to UK energy security, but does little to reduce consumer prices.

The implementation of the IED means that coal-fired stations must either become cleaner still or cease to generate by the early 2020s. The rising carbon price floor reduces their competitiveness, and together these policies significantly reduce the total remaining coal capacity – much of it to be replaced by gas. Those coal stations still running often do so as part of the Capacity Market, receiving payment in return for availability. Opportunities for grid-scale storage remain limited.

The majority of remaining nuclear capacity has shut down by 2023 despite debate over allowing continued operation with extended licences. Sizewell B remains the only operational plant from the earlier generation plants. The debate about new nuclear capacity is still running and no site for a high-level waste repository has been found. The plant commissioned in the mid-2010s is still being built owing to regulatory, legal and technical difficulties. The government increases the subsidy available in order to encourage investment in new nuclear build but this results in only one or two new agreements.

Demand Side

Smart metering in the residential sector results in small sustained savings in the region of only 2-3%. However, more small and medium-sized enterprises are signing up to various services to help manage use and improve efficiency, with third party demand aggregators using half-hourly data to negotiate better deals for business customers. Large industrial users continue to provide near-to-real-time data and this spreads slowly into the smaller-scale commercial sector. As prices rise, smaller industrial users see advantages in contracts that had previously only been relevant for large users, and some participate in the Capacity Market through aggregators. More sophisticated agreements between suppliers and consumers emerge and the ‘Big Six’ power companies, still dominant, compete to provide the most flexible contracts. There is therefore a small amount of DSR available in the system that can be called on at time of peak demand.

Networks

Communication networks gradually improve and expand to give better coverage. Although now smarter as a result, the lack of vision of policymakers and co-ordination from major industry players means that the power system is developing in a piecemeal fashion. As the industry remains fragmented, the split incentive problem persists, under which benefits do not accrue to those paying for them.

As a consequence of the Renewable Heat Incentive the number of ground- and air-source heat pump installations rises, predominantly in areas off the gas grid. Where clustering occurs, DNOs experience some localised difficulties at low voltage substations as locations off the gas grid correlate with the weaker parts of the distribution networks. Substations are simply upgraded by traditional means to handle the additional demand as the costs of smart solutions are still too high.

2030 – 2040

Supply Side

Having reached 20GW of total wind capacity in the early 2030s, there is a need for some smart technology in certain areas to handle the more variable supply. Although research and development continues and improvements are being made, the relative costs of storage technologies are still considerably higher than those of gas-fired peaking plant. The generation mix consists of a small number of nuclear stations, many gas generators, and an assortment of renewables. These are deployed in an ad hoc fashion and consist mainly of wind but there are also some medium-scale solar PV farms, and a very small amount of newer technologies, such as tidal-stream devices. Modest amounts of microgeneration feed into the grid, but remain unproblematic for the DNOs.

Demand Side

In-home displays for smart meters remain a niche market but those available now have greater functionality. They are popular principally with customers with an active interest in their energy consumption or those who own an EV and are attempting to get the best value when charging it. The rate of heat pump installation has dropped as many of the properties that would benefit the most have had them installed.

Networks

Early in the decade EVs are still relatively uncommon and tend to be found only in affluent urban areas, meaning DNOs rarely have to consider the impact that they were having on the local distribution network. More often than not, simply increasing the capacity of local transformers is sufficient to handle the increased power flows. Monitoring equipment is sometimes installed in areas that are likely to see rising numbers of EVs so that the networks are able to spot any congestion before it becomes problematic.

2040 – 2050

Supply Side

Carbon capture and storage (CCS) for coal plants develops to the point where it can generate competitively, although this reduces the overall flexibility of the system and has an impact on consumer bills. The UK meets neither European nor domestic legislative renewables and emissions commitments. Investment in gas as a 'bridging fuel' has left a legacy of gas power stations that are expensive to close and the country therefore attempts to meet climate obligations through the purchase of carbon credits on the international market, which is increasingly expensive. A small amount of nuclear still contributes to the generation mix, although this is scheduled to cease operating in the decade following 2050.

Demand Side

Although the growth of electricity demand is offset to some extent by energy efficiency programmes, they have not been sufficiently successful to reverse the trend of rising demand over the decades. This increase has not been accompanied by a rise in demand side flexibility, and the familiar peaks in the demand profile are exacerbated by the rise in demand from the (albeit limited) adoption of heat pumps and EVs. The costs of constructing and operating a much greater amount of gas peaking plant and, making the necessary network upgrades, are borne by consumers.

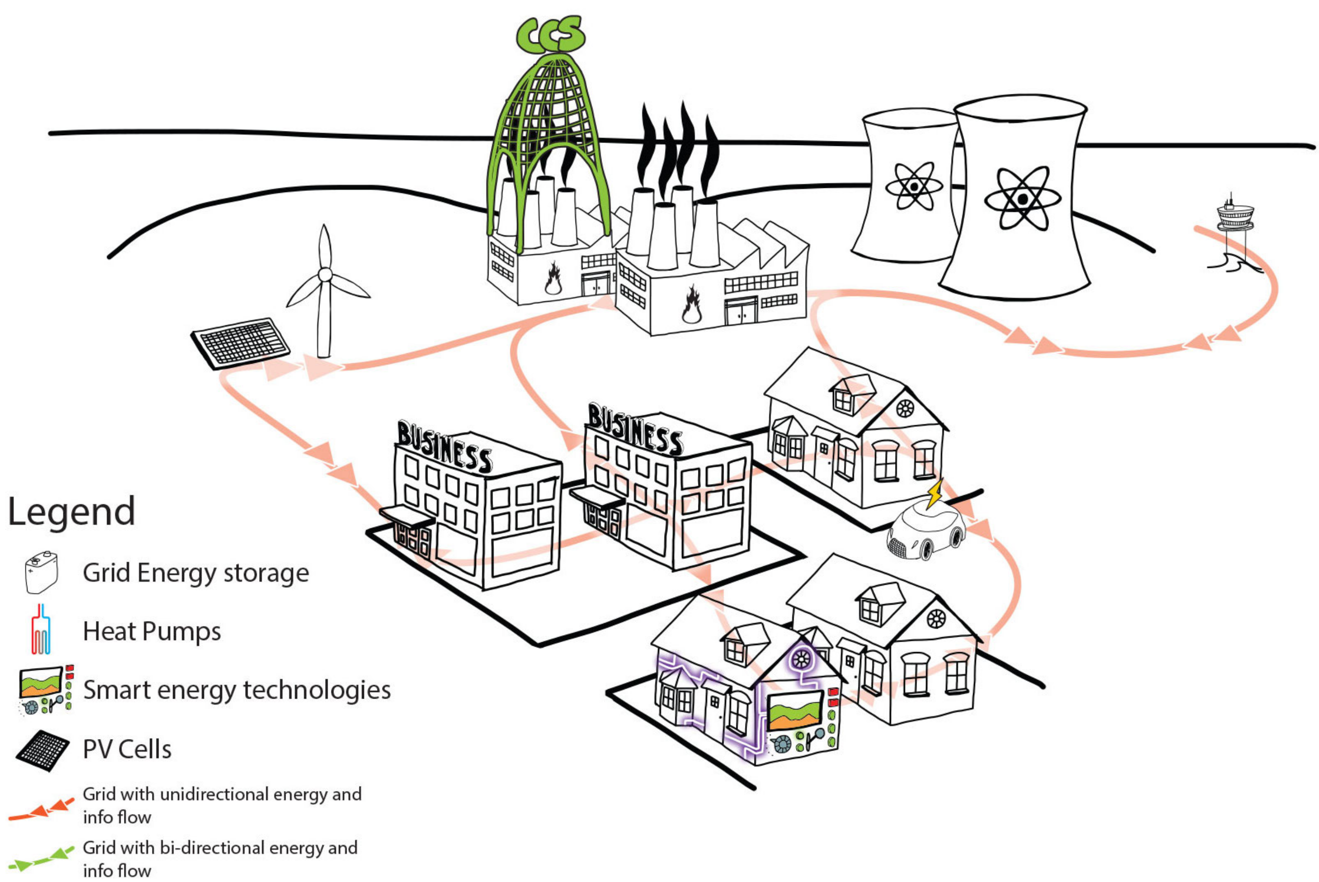
Networks

The distribution network has patches of smartness that were developed to deal with demand fluctuations as necessary. EVs become more of a problem in some urban areas. Additional adoption of heat pumps also places further stresses on the system. Apart from this, the distribution networks look and function similarly to the last 20-30 years. This means that research and development is limited, but those companies actively pursuing smart technologies are achieving more success in exporting technology and services.

State of the world in 2050

In the Minimum Smart scenario the lack of drivers for system change means that the energy system has seen the least movement from the current profile (Figure 6). Power is generated in bulk at remote locations, transmitted nationally and then distributed to households and businesses through the distribution networks. The generation profile has altered slowly over four decades to 2050 – old nuclear power stations have been replaced with new ones and renewables make up a greater proportion of the overall mix. Gas generation has supplanted coal to a large degree. There have been substantial upgrades to parts of the distribution networks to accommodate increases in demand in places but operationally and organisationally the DNOs are very similar to how they are in 2014. Most householders remain passive and do not take action to control and reduce their energy use and their engagement with the energy is limited to the size of their bill. Very few consumers adopt distributed generation technologies and the widespread conception of top-down, centralised generation perseveres. A lack of consumer trust in utilities and the absence of significant new entrants to the sector, combined with a lack of engagement, means there are insufficient drivers for significant uptake of demand side management (DSM).

Figure 6. Minimum Smart Scenario



3.2 Groundswell

Defining characteristics:

- Strong and growing interest in home energy efficiency and alternative energy technologies by consumers.
- Adoption of distributed generation through community projects, with some moving away from reliance on grid electricity.
- New market entrants in energy supply, aggregation, and growth of energy services companies.
- Few policy interventions, with the policy largely playing catch-up with public attitudes.

Now – 2020

Supply Side

The amount of wind generation on the system grows from 10GW, but development is largely at offshore sites. The Large Combustion Plant Directive ensures the closure of a number of coal-fired stations by the middle of the decade with gas generation taking its place. The ongoing public debate about a new wave of nuclear plants hampers attempts to mitigate the shrinking of the capacity margin.

Whilst participation in global gas markets helps security of supply, increasing dependence on imported gas exposes the UK to global price volatility as North Sea reserves continue to decline. As prices creep continually upwards mechanisms such as the feed-in tariff drive modest but steady growth in small-scale and domestic renewable generation. Signs of reduced reliability and the possibility of power outages also lead to growing interest in off-grid technologies. The 'doom and gloom' stories remain a favourite topic for the media, with evidence emerging that this is influencing public attitudes, encouraging energy saving and efficiency.

Demand Side

The national smart meter and accompanying communications infrastructures are successfully rolled out by 2020 and the billing accuracy achieved by automated meter reading is readily welcomed by householders, resulting in increasing awareness of consumption levels and a growing interest in efficient appliances. Many householders use their in-home display regularly; some begin to take an interest in cost savings and a market for in-home displays with greater functionality emerges. Concurrently with the meter installations there is a slow but steady rise in the number of heat pumps, boosted by the Renewable Heat Inventive. They are mostly taken up in areas off the gas grid, gas remaining the most cost-effective method of space and water heating.

Networks

The modest rise in small-scale and community renewables means that DNOs start to consider the technical and cost implications of accommodating reverse power flows. A greater amount of investment is allowed under RIIO-ED1 such that DNOs begin to channel investment into innovative solutions rather than conventional fixes. However, as growth of power-hungry technologies (such as EVs and heat pumps) is slow, advanced instrumentation is only being installed in the distribution networks on the basis of need and cost-effectiveness. Upgrades to increase the smartness of the network are restricted to areas with higher expected rises in peak demand and more complex load profiles – the latter often due to clusters of microgeneration typically occurring in rural areas.

2020 - 2030

Supply Side

Wind capacity reaches 20GW in the mid-2020s when several large offshore installations are completed. The Renewable Heat Inventive stimulates supply chains, skills and business models, improving the economics of CHP generation significantly. Additionally, the government grants local authorities greater control over energy issues, including power to ensure that benefits from renewables projects flow into nearby communities. A number of enterprising authorities start partnerships with businesses to operate CHP units, often using local biomass or biogas. District heating develops in suitable areas including new-build flats, tower blocks and warehouses with a high heat demand. Large-scale social landlords play an important role in driving energy-efficient new-build programmes, PV installation and whole-block renewable heating systems. Energy storage regulations are clarified alongside RIIO-ED2 in the early-to-mid 20s. As the decade continues, some storage devices are put in place for network management, but only in situations where the high costs can be recouped and/or where it provides a vital balancing function in the transmission network. Growth in wind and PV across Europe drives greater levels of interconnection, providing an important source of supply side flexibility.

Demand Side

Householders' understanding of their electricity consumption improves, and prompts greater interest in efficiency measures and heat pumps. Take-up of alternative tariff types grows, particularly among households possessing microgeneration and heat pumps. Residential aggregators emerge in such areas but in the absence of significant demand shifting, they do not play a major role.

Aggregators deal with both the domestic sector and commercial sectors trade on the secondary market; with generators looking to hedge risk relating to non-appearance penalties. Residential DSR is developing, but is in its infancy. Businesses consumers, particularly small and medium-sized enterprises, enthusiastically adopt advanced metering and sub-metering, flexible contracts, new tariff structures, and efficiency measures. Nationally, disaggregated data from smart meters is still not available to DNOs but as householders and businesses directly engaged with service providers receive benefits with no breaches to privacy being reported, trust in the use of data grows.

Local authority-run schemes that reinvest revenue from renewables projects in household efficiency measures are popular when well run. Clear communication of how they operate and transparent evidence that revenue is being reinvested effectively contributes to public acceptance of such ventures. The resulting awareness in energy and environmental issues helps to link the role of renewables in the generation profile, at both local and national levels, with personal energy use. The spread of these schemes is patchy and uncoordinated in both urban and rural areas. Some urban areas find the logistics too extensive to overcome; in others community groups have reached critical mass for efficiency and microgeneration projects to take hold successfully. Large concentrations of demand coupled with stronger and more effective governance capabilities result in economies of scale and greater returns to investment.

Networks

The clustering of heat pumps and microgeneration, and some of the local authority-led schemes cause localised network congestion. DNOs handle this by applying a range of smart technologies that enable aspects of active distribution network management. Some community schemes use small-scale storage technologies to balance their demand and generation profiles. Experience of being less reliant on grid electricity spreads and appeals to more communities. Some local authorities start to operate private wire networks, only using the grid for backup, but cost prevents this from becoming widespread.

Towards the end of the decade, regulatory reform allows the most advanced DNOs to take on more system management. They begin the transition to DSOs in those areas where 'smartness' has clustered. Technologies enabling voltage profile management, remote switching and demand management are introduced to manage power flows on critical circuits as an alternative to increasing network capacity. DSOs and newer market entrants also provide some ancillary services to the Transmission System Operator (TSO), replacing services previously supplied by transmission-connected conventional generation. Work begins on the trialling of heat storage to reduce and manage loads on distribution networks.

2030 - 2040

Supply Side

The growing collaboration between local authorities, network operators, and businesses starts to disrupt the top-down supply-driven electricity system paradigm. The growth in community schemes and onset of demand management means that the installed capacity of wind reaches 30GW by the mid-30s. This growth is split between onshore community-owned turbines and large offshore installations. Investment in interconnection adds flexibility and supports a growing European super-grid. The growth in the number of households that own and/or operate microgeneration and small-scale storage technologies is significant, particularly PV in urban areas.

There remains a substantial amount of gas in the UK generation mix, although the prospect of mandated use of carbon capture technologies causes investment uncertainty around the competitiveness of gas against renewables. The only nuclear-powered generators are the few that remain from the largely unsuccessful push for a new fleet that occurred in the 2010s.

Demand Side

The economics of EVs have been improving and they are now reasonably common in urban and suburban neighbourhoods. Whilst the grid requires reinforcement in places to handle the higher peak flows – particularly where clustering of vehicles occurs – networks are able to interact with the vehicles in order to smooth peaks. Innovative tariffs encourage consumers to accept some remote operation of vehicle charging. For example, network operators may contribute towards the upfront costs of the vehicles and guarantee the life of the battery in return for some control over how they are charged.

The growth of EVs triggers greater demand side flexibility and the aggregators that emerged in the previous decade now play a greater role, offering a range of services from instant supplier switching to network management and system balancing.

As R&D has improved the performance of air-source heat pumps, legislation is introduced to limit further growth of gas-fired heating systems in new housing developments. As business consumers see the benefits of time-of-use and flexible tariffs, some employees become interested in their domestic application.

Networks

As the 2030s progress, many rural areas source the majority of their electricity locally and rely less on the grid. DNOs regularly install sensors to improve network observability, and not just at the extremities of their networks. Most DNOs have some control over distributed generators – including electrical and heat storage – and so continue to develop as DSOs.

This gradual – though partial – reallocation of control from the TSO to the DSOs is mirrored by a shift in investment: spending to increase the capacity of the transmission system has been lower than had been anticipated, although it still serves large non-domestic consumers and towns and cities, and carries bulk national and international flows.

2040 – 2050

Supply Side

Centralised generation exists primarily to meet the needs of large towns, cities and industry: the bulk of which comes either from offshore wind or gas generators (some fitted with CCS). Strong integration with European networks adds flexibility, and smaller-scale generation from a wide range of technologies has grown and now makes up a significant proportion of supply capacity. Owners of large amounts of roof space commonly act as generators too, and commercial premises are able to provide demand side services by adjusting their heating and cooling needs, aided by a capacity market designed and operated in order to draw the maximum benefit from demand side measures before calling on generation.

Demand Side

Heat pumps and EVs often coincide in the same areas. Improvements in range and the national charging infrastructure mean EVs are popular across the country, with the batteries providing a valuable balancing function in areas with large amounts of renewables, which has been a major factor in the development of DNOs into DSOs. However, batteries have still not developed to the point where they can be used for dynamic storage at scale. The acceptance by consumers of time-of-use tariffs and the adoption of energy efficiency measures has helped to reduce peak demand, although significant demand shifting behaviour remains elusive. Although real-time price signals are available, residential consumers remain resistant, and only a small number of business customers are taking up services based on dynamic pricing.

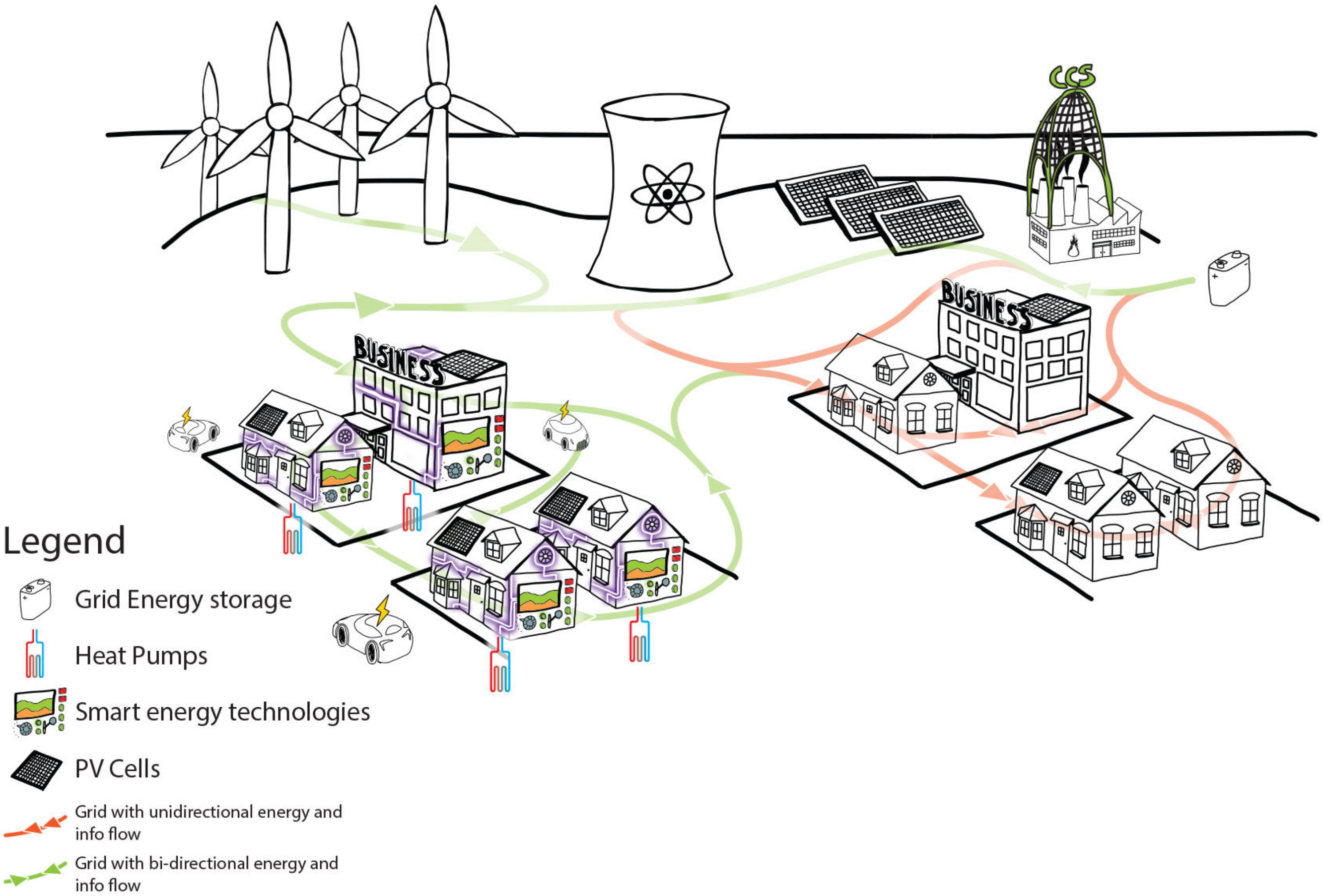
Networks

The transmission system provides important flexibility at times when DSOs cannot provide sufficient DSR and also serves areas that cannot balance their own power needs. It also carries bulk power from areas rich in generation, especially renewable resources. The increased quantity of generation in the distribution networks has reduced the load on the transmission system, and some of the skills and knowledge of active transmission network management acquired in previous decades have been transferred to the DSOs. Smartness in the distribution networks is patchy, causing some difficulty in urban areas where successful community or local authority schemes adjoin areas with less demand side engagement or where geography or property mix prevents the operation of cost-effective schemes. Some areas are keen to take even greater control by buying back their portions of the network, which presents complex regulatory and legal issues for Parliament and the regulator.

State of the World in 2050

This scenario describes a radical move away from the historical functioning of the power industry and a move towards a much more decentralised system in which 'prosumers' both contribute to and draw from the wider networks (Figure 7). A significant amount of electricity is generated at a household and community level, although large, centralised generation still has a role to play in meeting demand from urban centres and industry. A major driver for this kind of change has been consumer engagement, which has created demand for new energy services and pushed forward the evolution of the system. Network operators now play a much more active role in the management of their distribution systems.

Figure 7. Groundswell Scenario



3.3 Smart Power Sector

Defining characteristics:

- Consumers are passive, and largely resistant to demand side measures.
- Strong policy-led development of renewable energy sources.
- Network operators take the lead with innovation as it is necessary to handle rises in demand from EV adoption.
- The supply industry deploys smart technologies and techniques where a business case can be made to avoid network reinforcement costs.
- Grid-scale energy storage and international connections form an important supply side solution.

Now – 2020

Supply Side

Beyond the ongoing closures of large thermal plant (due to the Large Combustion Plant Directive) and remaining nuclear stations, there are no radical changes in the generation profile. Offshore wind generation grows in line with supply chain constraints and the availability of grid connections but well-organised campaigns prevent significant further onshore development. The government pushes ahead with plans to develop a new nuclear fleet to replace forthcoming closures, and a small number of new reactors are under construction by 2020.

Demand Side

Although energy suppliers successfully install smart meters in all residential and small-to-medium sized commercial properties by 2020, trust in the companies remains low as prices continue to rise. Optimism about the possible household savings soon wears off as negative stories about potential, suspected or actual privacy breaches emerge. The commercial sector is generally more accepting of the meters than the domestic sector. In addition to global gas markets, the policy support offered to conventional and renewable generation also inflates prices. Residential demand grows slowly with new sources of demand, such as EVs and heat pumps, remaining small in number and geographically dispersed. Small-scale PV installations have grown only very slowly as the feed-in tariff has been gradually reduced.

Networks

Emerging from successful Low Carbon Networks Fund and Network Innovation Competition projects, DNOs put in place selective monitoring and control equipment to assist with day-to-day management and planning. However, this is only progressing at the rate of their asset replacement programmes. A basic communication infrastructure is developed alongside the national smart meter rollout. The Data and Communications Company and Data Services Providers start to operate, but they only pass historical aggregated data to the DNOs, which have limited usefulness for network management.

2020 – 2030

Supply Side

By the middle of the decade wind capacity reaches 20GW, mostly due to ongoing policy support and accumulated offshore engineering expertise. Since the government gave communities a greater say in planning decisions, developers have largely abandoned trying to site onshore wind turbines. Further investment in renewables in encouraged by strong policy signals and government support – principally in the form of the EU Emissions Trading System, underpinned by the UK carbon floor price.

Gas generators still provide system flexibility, although wind generation capacity rises at a considerable rate and the TSO becomes concerned about managing periods of low demand and high generation; there is not always a ready export market or sufficient interconnector capacity. The fear is that prices may fall, adversely affecting investment in the industry. Regulatory reform resolves issues of DNOs owning and operating storage, and European targets for renewables, efficiency and emissions tighten. These provide impetus for R&D into system balancing and grid-scale storage technologies, paving the way for commercial development and new market entrants. Towards 2030 significant advances are made in energy storage technologies.

Demand Side

Residential consumers remain largely disengaged, and very little progress has been made regarding efficiency, load-shifting or demand reduction. As energy bills remain high, power companies remain a popular target for tabloid newspapers. The Green Deal, launched a decade earlier, received such little interest that the government quietly drops the idea of a replacement scheme. As it is apparent that residential load shifting on a large scale is unfeasible, legislation mandating many types of white goods to be responsive to abnormal voltage and frequency is enacted. However, some efficiency improvements are made where energy management is the responsibility of the landlord rather than the tenant, especially with social housing providers and commercial users.

Towards the end of the decade, EVs numbers increase as sustained policy and private sector momentum results in a growing charging infrastructure. Businesses form partnerships with public and private organisations to provide services to EV owners and car clubs. Many towns and cities have numerous charging points, and the highest rates of EV growth are found in affluent suburban neighbourhoods.

Networks

Surveys show consistently that consumers are unwilling to allow any further access to, or use of, the data that smart meters record. Although the aggregated historical data does help DNOs to plan investments and maintenance schedules, it does not assist real-time operation. The parts of the network with highest EV penetration almost require active management and the lack of observability has become an issue. If the present rate of EV growth continues, the business case for widespread monitoring equipment at low voltage substations will soon become realistic. As it seems that the existing smart meter infrastructure will be available to them, DNOs start to consider the value of creating dedicated metering and communications systems.

2030 – 2040

Supply Side

By the early 2030s, a number of new nuclear power stations contribute around 10% of the generation capacity. This helps to accommodate the growing use of EVs, improving diversity of supply, and moves the UK towards emissions reduction targets. By the mid-2030s there is around 30GW of wind capacity, although this is increasingly difficult to integrate due to the near-total absence of DSR. The construction of a multinational North Sea HVDC grid is expected to alleviate this to some extent.

Towards the end of the decade, power stations built during the second 'dash for gas' begin to face closure; those with lifetime extensions continue to operate but are subject to increasingly stringent environmental regulation. The flexibility provided by gas generation becomes increasingly valuable to the system, and many are granted extensions on this basis. Investment in R&D a decade ago has produced a small but growing number of grid-scale storage devices, a development that assures the investment community that the risks of constraining the growth of renewables can be mitigated.

Demand Side

The number of EVs rises quickly as higher sales in other countries brings down the relative price of the vehicles. This increases the size of evening peaks, which prove to be difficult to shift due to the very low levels of consumer engagement. Although vehicles are fitted with software that can take account of the network's frequency and voltage conditions, or even communicate automatically with the network operator, most owners over-ride these features. There is only a limited response to time-of-use pricing, as the incentives remain insufficient to change consumer behaviour. Lengthy studies reveal that consumer inertia and the 'hassle factor' are greater barriers to tariff switching and home improvements than previously thought. It becomes evident that only the house-by-house, street-by-street, refurbishment programmes carried out in some low-population Scandinavian countries would be successful at significantly reducing domestic energy consumption.

Networks

Increasingly sophisticated demand modelling using better quality historical power use data assists with network planning and asset management, ICT and HPC tools advance the point at which DNOs are now using near-to-real-time distribution system state estimation as a regular network management tool. The strong emergence of EVs creates significant challenges for DNOs, which in some cases is addressed by simply upgrading low voltage network capacity. In other areas, including some new-build housing estates, there is a business case for putting in place smart technologies from the outset. Other interventions by DNOs include improved monitoring and switching for network reconfiguration and increased types and levels of automation as networks edge towards active management. The improved network visibility assists with condition monitoring, asset management and planning.

2040 – 2050

Supply Side

The generation mix in the 2040s is characterised by a high level of renewables – predominantly large-scale offshore wind developments. Nuclear provides baseload generation, and by 2050 all of the country's unabated gas-fired power stations are expected to cease operation in order for the country's emissions targets to be met. With a rigid demand side there is a heavy reliance on storage and interconnection to provide supply side flexibility. A strongly integrated European electricity market and European super-grid bolster supply security across Europe, so less emphasis is placed on national security of supply.

Demand Side

Suppliers are considering the merits of the next generation of smart meters. However, given ongoing concerns about data privacy and public attitudes towards power companies, there is virtually no prospect of upgrading the original rollout. Various attempts have been made to encourage the use of smarter meters, but with little success. There are now a large number of EVs on the roads and a well-developed charging infrastructure along motorways, which increases baseload demand substantially. With little demand side flexibility, the government considers legislation to allow more effective management of this greatly increased demand.

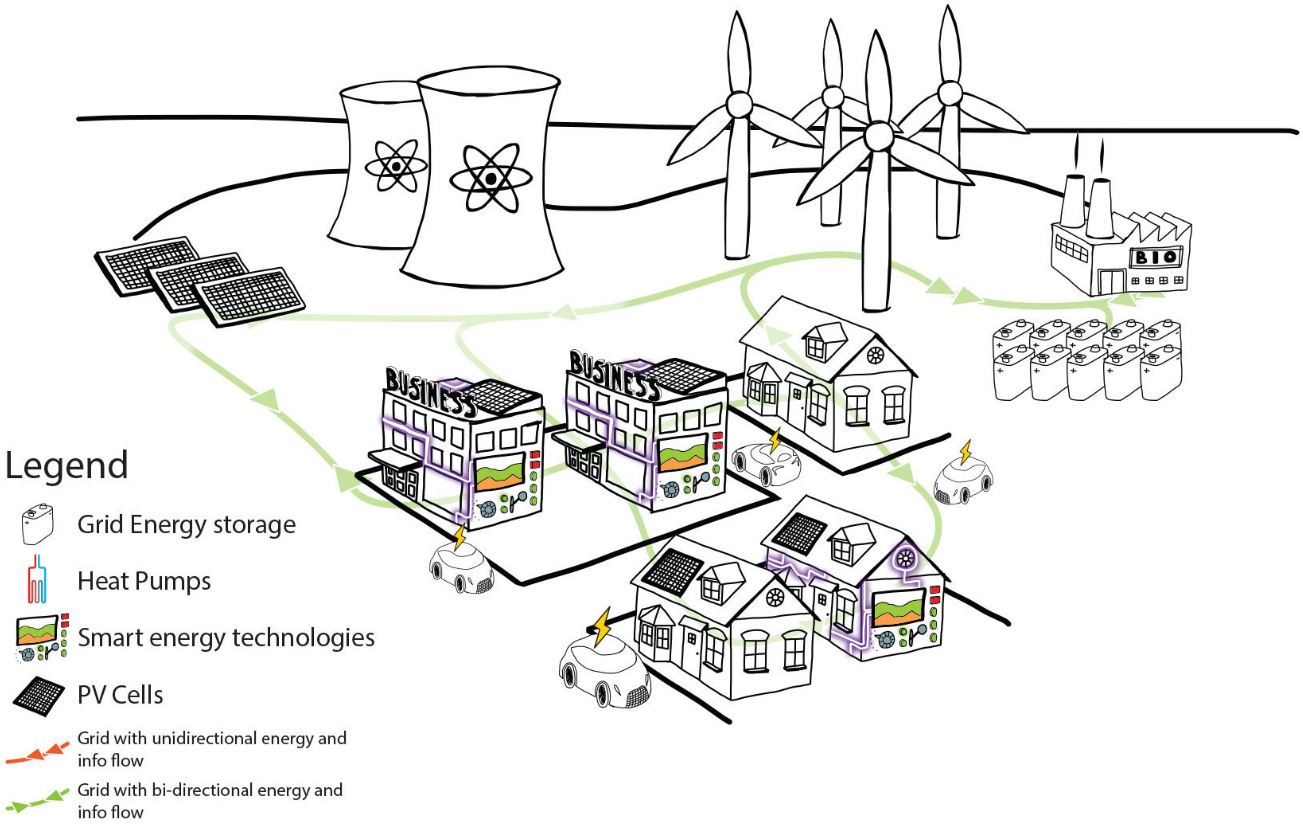
Networks

Active network management is normal at all voltage levels and spans of the transmission and distribution systems, and there is particular focus on parts of the low voltage networks, typically where EV clusters appear. Dealing with the rising demand from passive consumers over the last 40 years has forced the industry to create a largely smart grid, but with significant patches where simple reinforcement was the easiest and cheapest solution. The HVDC transmission system connecting regional renewable resources such as North Sea offshore wind, Spanish solar and Norwegian hydro to large centres of demand is operating and is expected to expand.

State of the world in 2050

Under this scenario government commitment to emissions targets leads to significant growth in variable output generation (Figure 8). Consumer antipathy prevents major smart developments at household and community levels, including DSR and very advanced metering and tariffs. However, the growing power demand resulting from the steady adoption of EVs combined with the amount of variable generation results in system balancing problems. The value of grid-scale storage becomes significant at this point, as the system can be managed much more effectively if it is developed and applied at scale. In the absence of storage, however, the difficulty of managing the system leads to a branching point: either consumers are offered extremely generous incentives in return for demand side flexibility or very expensive network upgrades are made to accommodate the much higher power flows. The roles and responsibilities of the DNOs, such as the level of active management, depend upon which branch is followed. As in the Minimum Smart scenario domestic consumers decline to become active service providers, and there is little in the way of innovative new entrants to pull them into changing their world perspective. Again there are insufficient drivers for significant uptake of DSM.

Figure 8. Smart Power Sector Scenario



3.4 Smart 2050

Defining characteristics:

- Strong and sustained policy commitment to renewable energy.
- Capital is available at competitive rates. Consumers are active and willing to engage with energy issues.
- Policy and regulation is supportive of low carbon technologies and associated infrastructure.
- DNOs invest in and develop widespread active network management techniques and technologies.

Now – 2020

Supply Side

The contribution of coal to the generation profile declines in line with the Large Combustion Plant Directive and (later) the European Industrial Emissions Directive. The amount of nuclear generation also falls as ageing plants close. Increasing gas- and biomass-fired generation fills the gap left by closing coal plant, and although replacement programmes for one or two nuclear plants are starting, the long-term economic viability of nuclear remains unclear. Interconnection capacity increases, taking advantage of arbitrage opportunities arising from the significant and growing wind and PV capacity across Europe.

Towards the end of this decade there is further and substantial market reform, as international developments – especially global climate agreements – lead the UK to reinforce its commitment to meeting its 2050 legislation. This leads to stronger policy measures in a range of areas including CCS and energy storage.

Demand Side

Smart meters are successfully installed with a strong and credible public information campaign despite some media scare stories. A dedicated intermediary Data and Communications Company is set up smoothly and the new company manages the flows of data effectively and securely. Various smart phone apps start to appear with particularly well-designed ones attracting significant numbers of users. This results in an underestimation of the impact of meters and in-home displays. The benefits of installing the meters become tangible to consumers as they begin to understand how their energy use fluctuates throughout the day and across the seasons. As the use of in-home displays is coupled with phone apps, many consumers focus on the potential for cost savings rather than the privacy risks.

Some larger city-based EV trials (UK and abroad) begin to allay range anxiety and have a marked positive impact on the general perception of the vehicles. This spurs new investment in R&D to improve battery performance, and there is optimism that this will allow economies of scale to take hold, improving EVs' competitiveness against conventional vehicles. Although the government continues to offer subsidies for the cars, in the absence of a national strategy for infrastructure development the new cars are small in number and confined to mostly urban areas.

Networks

A clear long-term vision from Ofgem encourages TSOs and DNOs to innovate and allows consideration of long-term investment that extends into the RIIO-T2 and RIIO-ED2 periods. The Network Innovation Competition proves effective at incentivising innovation in the transmission networks. Through RIIO, regulation begins to be effective in encouraging DNOs to innovate and adopt alternatives to traditional investment where financially viable. This helps to increase the capacity of existing network assets and to reduce the investment burden.

2020 – 2030

Supply Side

Despite missing the 2020 EU renewables targets, growth in both onshore and offshore wind means that they are reached not long into the decade.

Clear and effective policy and improved grid-access arrangements causes the proportion of variable supply to rise to 30GW by the middle of the decade. Much of this growth is in offshore wind, but biomass makes a significant contribution and early tidal stream schemes start to operate. Despite various technical and financial difficulties, a small number of new nuclear plants start to generate towards the end of the decade.

Innovation in interruptible contracts allows smaller consumers with non-essential shiftable power demand – such as industrial refrigeration, heat storage and some types of machinery – to offer demand side services. Whilst this provides a small amount of demand side flexibility, the much more substantial benefits from DSM in the residential sector are yet to be exploited. A substantial round of market reform passes in the late 2020s designed to boost competition and stimulate the provision of new and conventional services. Legislation passes that guarantees storage reliable access to market (within the constraints of network balancing), controls how and by what means networks and aggregators are able to exercise demand side control measures over appliances in customers' homes, and redefines the roles and responsibilities of DNOs, allowing them to own and/or operate generation and storage.

Demand Side

Greater pricing and costing transparency, growing energy awareness, and a long-term trend of rising energy bills leads householders to take a more active interest in reducing their energy consumption. This level of interest grows slowly through the first half of the 2020s led by younger more tech-aware urbanites whose salaries are stretched by housing costs. This results in modest but sustained behavioural changes, and a desire for a wider variety of tariffs to suit their needs. The real-time pricing information now available makes customer communication and pricing much simpler and somewhat improves the perception of power companies in the mind of the public.
Throughout the 2020s and beyond, the capabilities of in-home displays improve. As consumer interest grows, a market for devices

with greater functionality than the basic ones issued at rollout develops. These in-home displays are able to interact with household appliances and manufacturers of white goods increasingly supply inter-operable products.

A burgeoning aggregation industry maximises the value of DSR for commercial customers for both energy balancing and network management purposes.

Networks

Ongoing installation of monitoring equipment at substations means that DNOs develop better observability within their networks and are able to focus investment on those parts under greatest stress. This is a direct result of the regulatory changes made as part of RIIO-ED1, which enables DNOs to justify 'forward investment' in enabling technologies that help avoid expensive conventional capital expenditure on network reinforcement. Successful trial schemes to embed intelligence and automation in the networks are extended as experience spreads enabling DNOs to begin actively managing some areas where EV penetration is growing. This is aided by clarification from the regulator regarding the roles and responsibilities of both the TSO and DNOs. Consideration is given to potential conflicts that may arise from DNOs managing their own networks and the TSO managing the national system.

The rising price of heating fuels (in combination with incentive from the Renewable Heat Inventive) triggers many consumers off the gas grid to install ground- and air-source heat pumps to meet their heating needs. By the mid-to-late 2020s this leads to congestion on some local distribution networks as systems are frequently clustered in areas and installed at similar times.

2030 – 2040

Supply Side

By the start of the 2030s sustained policy support has led to the construction of several coal-fired power station fitted with CCS. The small number of nuclear stations also contributes to meeting baseload demand.

Even though the TSO and DNOs are gaining experience and confidence operating with less baseload power, gas-fired generation is still used at times of peak demand. However, legislation requiring that gas be fitted with CCS, and the consequent loss of flexibility, is adding impetus to the efforts to scale up the role of electrical storage.

Throughout the 2030s renewables and interconnection capacity grow, with connections to Ireland and Norway providing the UK with an important flexible resource that helps counter the less-predictable output from the large amount of offshore wind now contributing to the system. Construction of a European super-grid offers further potential for the accommodation of renewables in the UK system.

Demand Side

By the early 2030s, the majority of households have one of a range of more advanced in-home displays. Whilst the complexity of these varies, most are able to handle much more rapid forms of two-way communication with the customer via mobile phone apps. Growing participation in aggregation services results in lower household energy prices. A modest proportion of householders take advantage of dynamic and critical peak pricing tariffs, and new market entrants provide a range of energy services to consumers (as well as to network operators). These include the provision of heating and lighting by energy service companies rather than conventional per-unit energy sales. New entrants are able to team up with aggregators and network operators in order to offer consumers new ways of managing their energy use, allowing them greater control and opening up further potential for DSR.

The introduction of EU-wide EV charging infrastructure legislation a decade earlier has stimulated the number of EVs on the roads and changes the economics relative to conventional vehicles. This results in greater power demand in some areas, which causes stress on parts of the distribution network, particularly where air-source heat pumps – increasingly competitive with gas-fired central heating – become more common. This stimulates the development of DSM devices and tariffs to ensure that EVs do not draw charge during peak hours. Later in the decade, trials show that EV users can benefit from quasi-dynamic tariffs.

Networks

Monitoring and automation equipment is now widespread across the MV network, with patches of smart technologies in selected substations in the low voltage networks. To improve active management in these networks, DNOs look to introduce some control over the demand profile to reduce congestion where EVs are clustering. Through collaboration with aggregators, by the mid-2030s they are able to shift some residential load at times of peak demand. Under specifically defined conditions to ensure stable network operation, DNOs are being allowed access to short periods of detailed near-to-real-time data. This remains patchy as the smart meter communications networks are still developing beyond the basic original installation.

2040 – 2050

Supply Side

The power generation system is now able to rely on a wider range of sources: offshore and onshore wind, gas, nuclear, tidal stream, PV, some biomass and small amounts of wave power. Grid-scale storage plays an important balancing role with several technologies with different operational characteristics. Gas-fired stations still play a significant role, although their flexibility is constrained by CCS technologies. The global development of demand side technologies and techniques, in tandem with high fossil fuel prices, means that DSM is often more cost-effective than peaking plant. The nuclear stations built in the 2020s provide baseload generation pressure to start planning for their replacements begins to build.

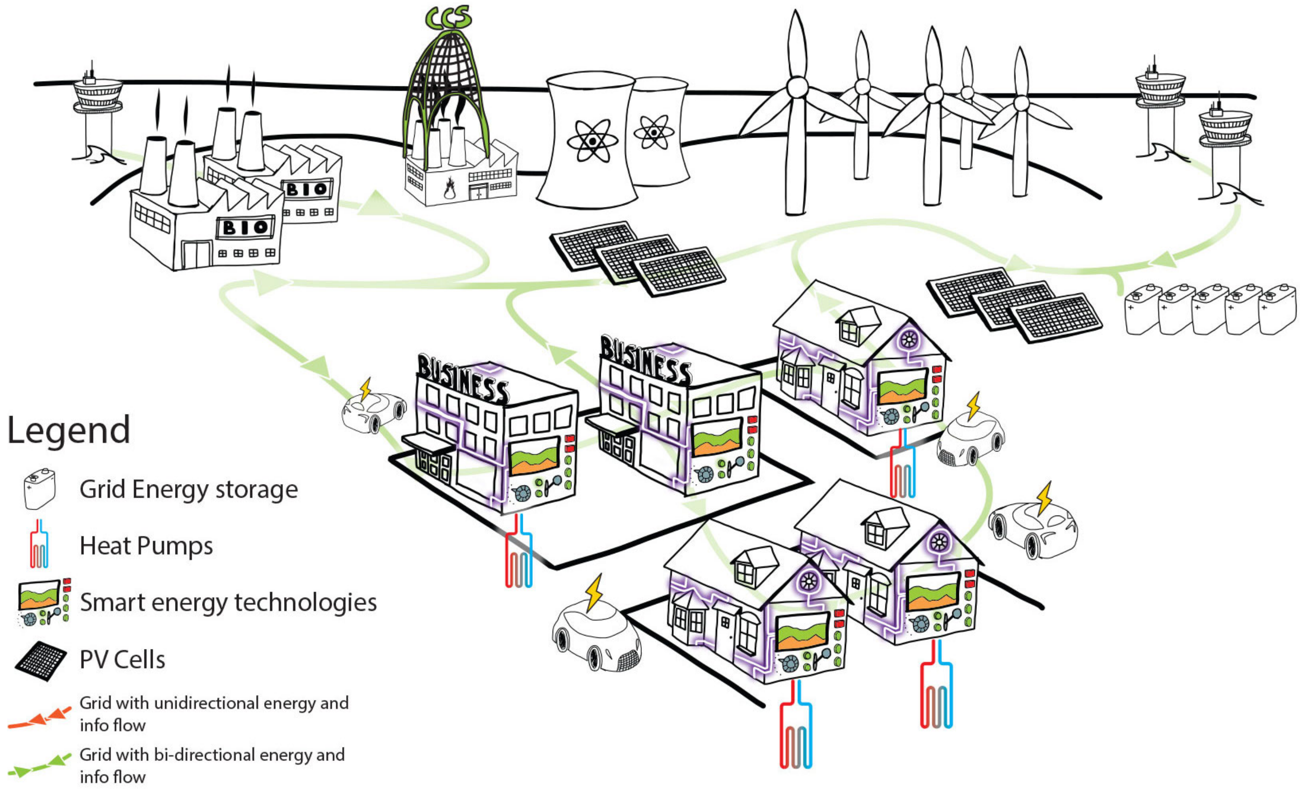
Demand Side

People who grew up with in-home displays controllable via phone apps are energy literate and start families of their own. For a significant and growing proportion of the population, energy conservation is a normal activity and an important consideration when buying a house. Low efficiency homes with higher levels of energy consumption are unpopular and clearly discounted in the housing market because costs of heating and/or insulating them to a decent standard. EVs are prevalent and the tendency for them to cluster requires that owners take part in DSM as part of the ownership package. For some DNOs this includes the use of specially-designed time-of-use tariffs and critical peak pricing.

Networks

Although construction of a European transmission network and a North Sea offshore grid are not yet finished, the parts completed add a robustness that TSOs and DNOs can exploit at a subnational level. Cost-competitive storage technologies assist with the active management of networks where EVs, heat pumps and PV are commonplace. Homes, particularly those that have electric heating or own an EV, can interact with the local network via their phone or computer in order to choose how and when the DNO or a third party can enact demand side measures. Consumers are accustomed to communicating with the network operator as well as their supplier – indeed, in some cases these two roles have merged, with single companies providing both services. Despite the well-developed demand control abilities of network operators there has been an ongoing need to make very significant network upgrades in areas where demand has risen.

Figure 9. Smart 2050 Scenario



State of the world in 2050

This scenario can be seen as one in which many drivers come together to lead to a future in which 2050 emissions and renewables targets are met through a combination of top-down policy interventions and public willingness to engage (Figure 9). There is a general consensus around the need for action to tackle climate change and an acceptance that it will be funded largely through energy bills. Consumer engagement makes possible demand side measures that allow large amounts of renewables to be accommodated into the generation profile, although there is still a large role for baseload generation. Network operators play a much more active role in system balancing and whilst it was initially possible to delay significant network reinforcement with the application of smart technologies, ultimately the ongoing electrification of heat and transport has meant that substantial conventional investment has been necessary.

3.5 Comparison of scenarios

Table 3, below, provides a brief overview of the differences in the main characteristics of each of four scenarios. The number of bullets conveys the comparative extent to which notable possible characteristics of the UK's future energy system is apparent in each scenario. A brief glance will show, for example, that the role of residential consumers in the Smart Power Sector scenario is minimal compared to its role in the Groundswell scenario. The list of characteristics is not exhaustive.

Table 3. Comparison of scenarios

Function	Minimum Smart	Groundswell	Smart Power Sector	Smart 2050
UK policy commitment	•	• • •	• • • •	• • • • •
EU policy strength	• •	• • • •	• • • • •	• • • • •
Supply				
Large-scale renewables	• • •	• • • •	• • • •	• • • • •
Decentralised renewables	• •	• • • • •	•	• •
Nuclear	• • •	• •	• • • •	• • •
Unabated gas	• • • •	•	• • •	•
Carbon capture and storage	• • •	• •	• • •	•
Grid-scale storage	•	• •	• • • • •	• • •
Interconnection	• •	• • •	• • • • •	• • • •
Demand				
Tariff complexity	• • •	• • • • •	• •	• • • • •
Advanced smart metering	• •	• • • • •	•	• • • • •
Electrification of heat	• •	• • • •	•	• • • •
Electrification of transport	• •	• • •	• • • •	• • • •
Industrial and commercial DSR	• • •	• • • •	• • • • •	• • • • •
Residential DSR	• •	• • • • •	•	• • • • •
Networks				
Advanced monitoring and controls	• •	• • • •	• • •	• • • • •
DNO's consumer data access	• • •	• • • •	•	• • • • •
Active network management	•	• • • •	• • •	• • • • •
DNO's own and/or operate generation	•	• • •	• • • •	• • • • •
Smart Grid Services Enabled				
Balance a large amount of renewables		✓	✓	✓
Greater observability and controllability of the grid	✓	✓	✓	✓
Enable deployment of DSR technologies		✓		✓
Active network management				✓
Integration of active loads (heat pumps & EV's)		✓	✓	✓
Allow integration of energy storage			✓	✓

3.6 Switching between pathways

One of the benefits of the FAR methodology is the possibility for switching between the different scenarios, which can be seen Figure 5. As the pathways begin to take shape as part of the FAR process, it becomes clear that there are points at which the routes can diverge, converge or 'jump' from one to another. Merging points are less common than branching points and tend to occur less far into the future, thus demonstrating alternative routes towards a given endpoint, whereas branching points can be seen as points in time where critical events occur that will shape the future (often, but not always, through an active decision-making process).

In addition to merging and branching, there are points at which a given pathways can 'switch' from one to another. The Faustian Tree developed as part of the FAR process present a number of points where it is possible to switch between pathways. Clearly, looking at the diagram, there are a number of places where the pathways overlap. We focus on and expand two of these below.

Switching away from smart power sector

Smart Power Sector progresses to a point where it is essentially forced to switch into another scenario due to active resistance from the public in the form of a refusal to participate in any demand side measures whatsoever. The way in which such an obstacle is tackled constitutes the branching point; in this case, how demand side inflexibility is addressed dictates whether the scenario switches to Minimum Smart or Smart 2050 (see below, The Consequences of Switching Pathways). If economic signals are increased to such an extent that DSR is initiated (or it is perhaps mandated), then this improves demand side flexibility and allows further renewables development (potentially at high cost). Such an approach may be economically and/or political undesirable and supply side flexibility may be the preferred option, owing either to cost or political expediency. In this instance the pathway would switch to Minimum Smart, and a system characterised, presumably, by a relatively larger proportion of gas generation.

Branching point: policy decisions

Box G in the Faustian Tree represents a point in future where the effects of the smart meter rollout on consumer engagement are being felt, and where a significant policy decision concerning generation is taken. Such a decision is very likely to be influenced by a wide array of factors, including international climate negotiations and global energy markets. A strong policy decision in favour of renewable generation sends the scenario down a very different pathway – one requiring a much higher level of consumer engagement – than a policy decision that favours gas, which may be a consequence of global shale exploitation and falling gas prices, for example. This branching point is the first point at which the Smart 2050 and Smart Power Sector scenarios diverge.

The consequences of switching pathways

Switching between pathways should be interpreted as moving from one scenario to another that is broadly similar to the destination scenario and not necessarily identical. It is also important to note that switching from one pathway to another may well involve going effectively 'back in time', similar in nature as the decision-making and investment times involved would mean the destination pathway would be less developed than if it had been followed from the beginning. Switching can therefore be costly in terms of time and resources and is likely to have a significant impact on all factors – consumers, markets, networks, generation etc. Whilst in most cases it will be a setback, it can also be seen as an opportunity to move from a pathway where environmental objectives are unlikely to be met to one in which they are within reach, although more expensively and later than might otherwise have been the case.

3.7 Wildcards

We have located 'wildcards' throughout the scenarios. These are events that would represent a shock of some kind to the energy system and would necessitate some form of response. Although several of these wildcards could fit into any scenario, we have generally located them where they are either most likely to occur or have the most intuitive 'fit', or where their occurrence would be likely to have the most significant impact – perhaps leading to a switch from one scenario to another (Table 4).

For example in the case of the Major Nuclear Incident wildcard, a rapid phase-out of nuclear generation under the Smart Power Sector scenario might result in either a sudden 'switching on' of consumer engagement as the public is prepared to accept voluntary or enforced behavioural change (which is not without precedent – e.g. as seen in Japan following the nuclear incidents in 2011), or the complete absence of such public willingness may lead to the hurried construction of a large amount of gas generation. In this situation, therefore, the pathway may switch either to the Smart 2050 or to the Minimum Smart scenario respectively. We highlight that such events often result in change that represents a radical departure from the status quo – something which many scenarios project do not attempt to address but are nevertheless important to consider.

Table 4. The effect of wildcards on scenarios
Re-nationalisation: Smart Power Sector
Public anger towards power companies reaches such a pitch that the industry is renationalised wholesale and paid for in part through general taxation. Costs go up as inefficiencies creep in but there is a much greater level of support for decarbonisation.
Break-up of utilities: Minimum Smart
Legislation limits the size of power companies, which then find it difficult to secure funding for large renewable projects. Finance is more accessible for thermal plant, so decarbonisation falters. Consumer prices fall, however.
Nuclear fusion breakthrough: Minimum Smart
With less need for DSM, the current peaks in demand are amplified by the adoption of electric heating and transportation. Very significant upgrading of low voltage networks is required in order to handle this growth in demand.
Getting rid of charging codes: Smart 2050 and Smart Power Sector
Action is taken to modify the charging methodologies and associated codes as they apply to DNOs, such that charges for load and generation (including storage) connected to the network are amended and that changes outside specified limits in either category have to be communicated to the DNO. This allows DNOs to have greater knowledge of installations across their networks and helps to reduce, for example, the impact of clustering of EVs and heat pumps. This could apply more strictly to the industrial and commercial sectors as desired and as appropriate to the scenario.
Cyber-security disaster: All Scenarios
The hacking of smart meters on a large scale demonstrates the inherent vulnerabilities of the system. Customers become very reluctant to share any data beyond a basic meter reading on a monthly basis, making it much more difficult for DNOs to plan future investments. Conventional reinforcements favoured over smart technologies.
Reports of smart meters catching fire (for example): Smart 2050
Negative press coverage of the dangers of smart meters, even though there is little evidence of this, leads to widespread public resistance, making much needed DSM much more difficult to implement.
Another major nuclear accident: Smart Power Sector
A major nuclear incident results in huge loss of public confidence and a political decision to phase out nuclear generation rapidly, resulting in a shift to renewables. The public is much more accepting of the necessary demand side measures and distributed renewables receive a major boost. Networks are required to act rapidly to accommodate the change in supply profile. *Shift to Smart 2050.* Alternatively, consumer intransigence results in a shift to gas generation as it becomes clear than demand side measures will be impossible to implement. *Shift to Minimum Smart.*
Growth of energy co-operatives (similar to Germany): Smart 2050
The emergence of the type of energy co-operative seen in Germany, in which communities retain (majority) ownership, reduces the dominance of large industry players. DNOs need to respond to the rapidly growing amount of distributed generation in the networks. *Shift to Groundswell.*

Table 4 cont. The effect of wildcards on scenarios
Emergence of a European regulator: Smart 2050
Increasing energy market integration, regulatory co-operation between member states, and pressure to minimise the cost to the consumer of large-scale renewables leads to the emergence of a body of EU regulation and ultimately to an EU-level regulator. This body takes on increased responsibility over time, with Ofgem moving from the responsible body to a facilitating body. The move is driven by the European Commission to secure reduced costs in meeting EU wide renewable energy targets via closer integration. There are various possible actions, representing different levels of integration. These include integrated forecasting of renewable energy and more strategic interconnection and infrastructure planning. It might also act as a driver for integrated innovation projects relating to smarter energy delivery.
Scottish Independence: All Scenarios
The impacts of Scottish independence are unknown to a significant degree. Independence would leave Scotland with more generation capacity than it requires as well as a large fraction of wind, wave and tidal energy potential. The nations may develop divergent regulatory framework but there is a significant chance that a single market might be maintained across the current GB territory. Some Scottish political actors have expressed a desire for this but this may not be advantageous to all parties. Scottish generators would have little option other than to sell via the England interconnectors which may have impacts on price. Both Scotland and the reduced UK may have to renegotiate renewable energy targets with the EU and this might be complicated by the EU's position on Scotland becoming an independent member state. Given the reduced UK's lessened potential for renewable generation it may no longer need to import as much from Scotland as is currently the case. This might have implications for how much smart technology is needed to facilitate intermittent generation and where the costs of facilitation would be met.
Climate Impacts: Groundswell and Smart 2050
As summers become hotter reverse-cycle heat pumps become a more attractive investment for many residential and commercial premises. While this drives up demand over the summer (and reduces network capacity) it also increases the potential for DSM.

Social and Spatial Implications

4

This chapter introduces the findings from a number of public workshops, and examines the social and spatial implications of our scenarios.

4.1 Public Acceptability

Participants in the four public workshops reflected a range of geographic, demographic and educational backgrounds, as well as home types and smart grid-relevant experience. This section summarises the main findings from (a) the questionnaires and (b) the qualitative analysis of the workshop discussions, on smart grid experience, knowledge and attitudes and responses to the draft scenarios.

Prior experience and knowledge of smart grids

In respect of relevant experience, around half (53%) owned timed appliances, most commonly central heating or washing machines, although only 11% were on an Economy-7 electricity tariff. Most said they were very (26%) or quite (57%) satisfied with the way they receive their electricity bills, but knowledge of the electricity system and of smart grids was relatively low, (see Figure 10) – although higher for rural (mean 2.6) than urban respondents (1.8). Nevertheless, there was interest in all smart grid-related topics, notably saving energy (Table 5).

Informed opinion about smart grids

Following the workshop, participants' informed opinions on smart grids were elicited through questionnaires. Attitudes can be characterised as ambivalent (Figure 11); that is, smart grids are thought to afford both benefits and risks. It is noteworthy that the balance of benefits to risks is greatest for power companies, whilst somewhat higher risks are believed to befall consumers.

Questionnaires also asked about the nature of the risks and benefits perceived for consumers, private companies, and society in relation to smart grids. The most common types of consumer benefit cited were lower energy bills and lowering energy use generally. Benefits cited for private companies were more varied but also included financial benefits, improved efficiency and system performance. In terms of societal benefits,

Figure 10. Self-reported knowledge of electricity system and smart grids across participant groups (pre-workshop)

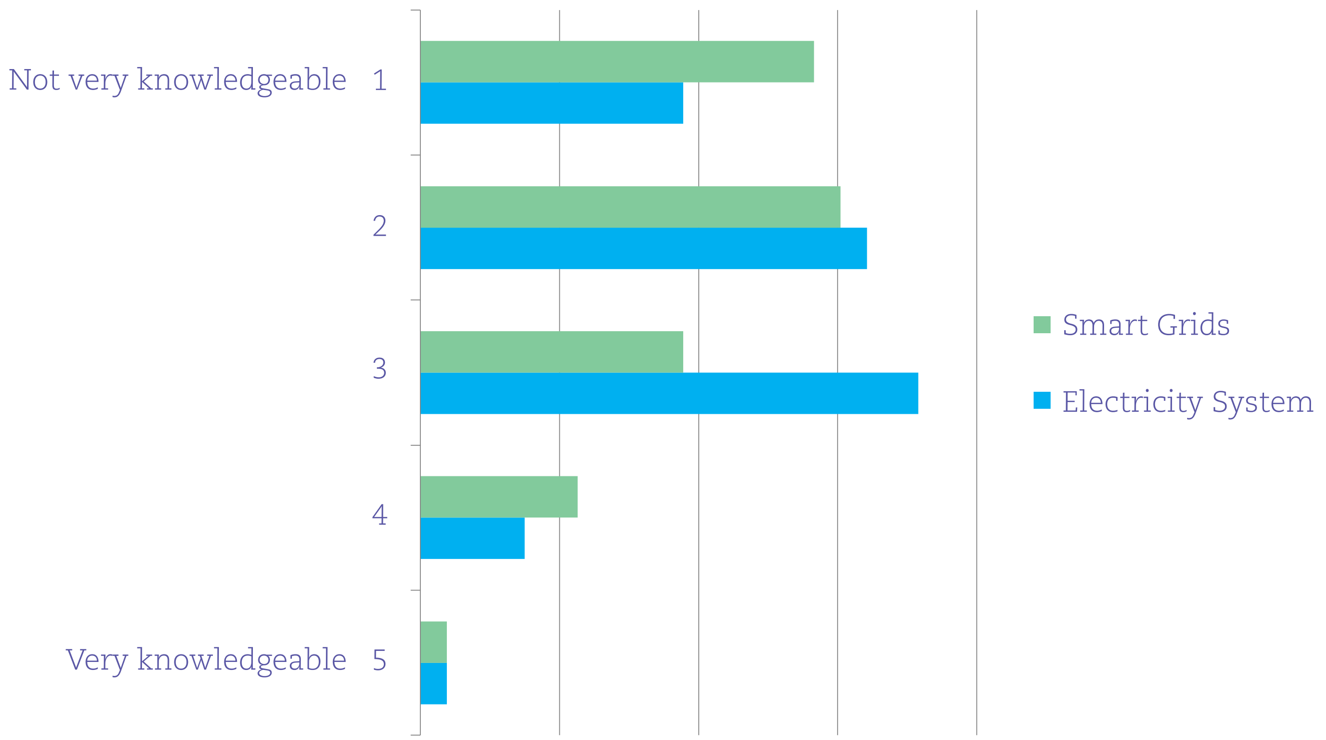


Table 5. Interest in smart grid related topics (pre-workshop)	Mean	SD
Receiving lower energy bills	4.6	0.7
Lowering my energy use	4.5	0.9
Owning more energy efficient appliances	4.4	0.7
Lowering our emissions	4.3	0.7
Being able to monitor energy use at room/appliance level	4.3	0.9
Using new technologies to reduce fuel dependency	4.2	0.9
Becoming less reliant on fossil fuels	4.1	0.9
Sourcing more energy from renewable resources	4.1	1.3
Producing energy at community level	3.9	1.1
Producing my own energy	3.8	0.9

* 5-point scale: 1 = Not at all Interested; 5 = Extremely Interested

environmental benefits (e.g. reduced emissions) were most commonly cited, followed by improved public awareness, reduced bills and fewer blackouts.

Consumer risks cited were dominated by privacy concerns, though costs, reliability and control issues were also mentioned. Respondents were less certain about risks to power companies or societal risks. Of those mentioned for companies, financial risks were most prevalent while excessive control by power companies was cited by several participants, with respect to broader societal risks.

Responses to scenarios

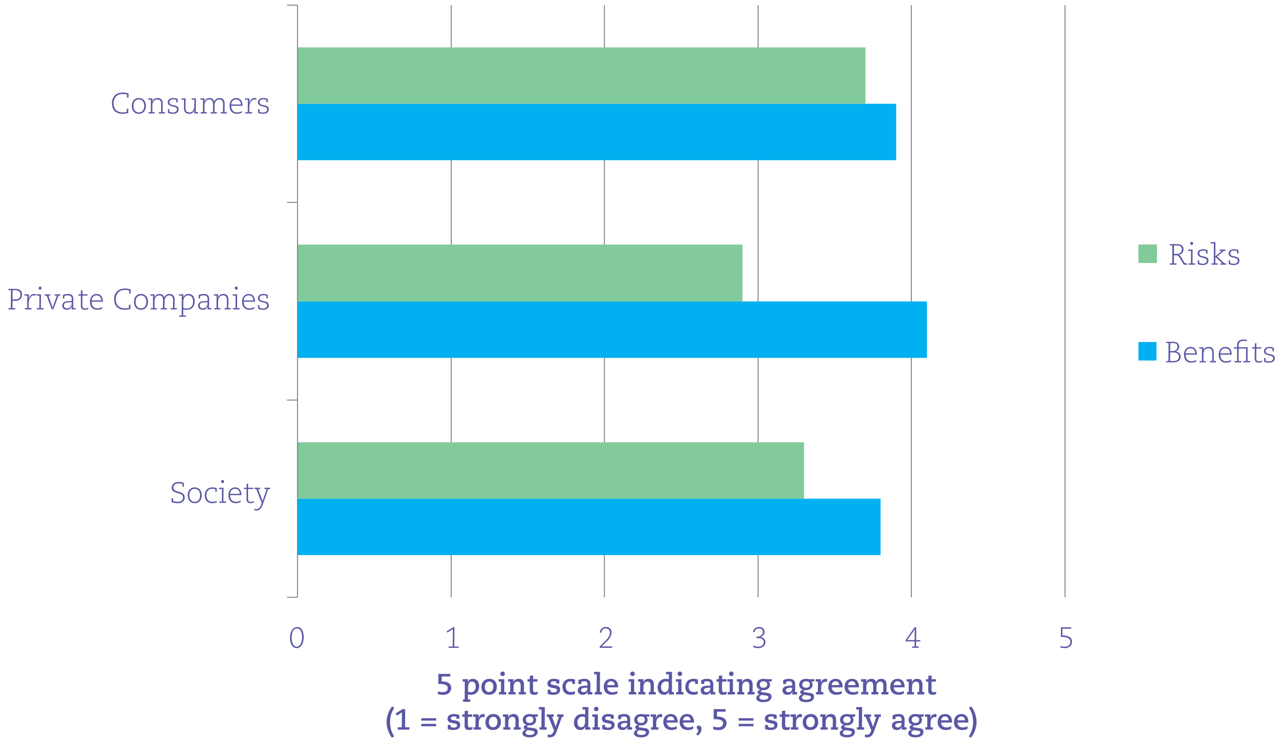
In order to engage workshop participants with the four scenarios, narrative storylines illustrating an individual's day-to-day life in the case of each scenario were created and presented to participants[v]. Workshop participants tended to view the Minimum Smart scenario as bleak, partly because it involved people having to monitor their energy use very closely, and partly because it was anticipated that technology would have developed far more by 2050. However, it was viewed as realistic in the sense that energy bills were continuing to rise:

> *'Well it's just like they're not really enjoying life. They're constantly concerned about cutting their energy bills down; fair enough but they're not really enjoying their life at home.'*
> *(R4, Rural A)*

The idea of having to pay more attention to energy use was perceived as an extra pressure in already difficult and time-pressed lives. Despite this resistance to monitoring, smart meters tended to be viewed more positively, as a way to help consumers save money and cut consumption. Some did question why they were being introduced, as it was perceived that helping to reduce customer bills was not in the interest of power companies. In addition, it was assumed that smart meters would need to consume energy themselves in order to function. There was also speculation that smart metering would lead to family members obsessively monitoring consumption, causing tension in households. Overall, consumers would need to be convinced of a clear benefit in order to guarantee widespread adoption of smart meters.

[v] Note that draft, rather than final, scenarios were presented at the public workshops and that revisions to the scenarios were made following a project advisory group meeting. In particular, an earlier scenario referred to as 'Partially Smart' was modified to 'Groundswell' by highlighting and expanding the scope of community energy schemes as the key scenario driver. As these schemes were already included in the draft version, the results remain applicable. The revisions in the other scenarios are minimal.

Figure 11. Perceived risks and benefits associated with smart grids (post-workshop)



Participants were also asked whether they would like household appliances displaying energy usage. Answers here varied considerably. It was thought that having displays would increase awareness of usage and may be useful for larger appliances such as washing machines. Displays were likened to having energy efficiency stickers on new appliances. There was some resistance to replacing old but reliable appliances, with the underlying assumption that older appliances were better quality. It was often assumed that 'smart' appliances would be more expensive, presenting a very practical barrier to ownership:

> *'That's the problem, I worry about the smart appliances being out of my reach, my financial reach, or I'll end up getting them on hire purchase and paying right through the nose' (R1 Urban A)*

The scenario Smart Power Sector was viewed as a more positive version of the future when compared with the Minimum Smart scenario. It was seen as more developed and futuristic, and for this reason a more likely portrayal of how 2050 might be. However, debate concerning the collection of personal data and how it might be used dominated discussion. Participants questioned how consumers would benefit from allowing personal data to be collected, whereas it was automatically assumed that power companies would reap financial rewards from such an exercise:

> *'Most people just want to know what they're paying for is efficient and that they're getting good value for money [...] the energy companies are making billions out of us, it doesn't matter how energy efficient you are, they're all creaming off and making a fortune' (R2, Rural B)*

Participants also questioned the type of data to be collected. Anonymised data to establish trends and help smooth running of the network was seen as far more acceptable than data traceable to people or households. When talking about future developments, participants were often cynical over the extent to which change would be forced upon them, and what would be a positive choice actively taken. Participants wanted reassurance that there would be legislation in place to protect their data, prevent identity fraud, and that it would be used specifically to improve service and infrastructure. The benefits from data sharing would have to be evident.

The Groundswell scenario was viewed as a more realistic representation of 2050 in that it seemed sufficiently more advanced than either the Minimum Smart or Smart Power Sector scenarios. Despite further changes made to this scenario following the public workshops, the key finding, on the acceptability of spatial variation in types of technologies and services enabled via smart grids, remain largely applicable in this community-led future. Participants were divided about how positive this version of the future was.

In terms of first impressions, groups liked the idea of getting a larger proportion of energy from renewable sources. Yet when introduced to the idea of spatial variation in the types of technologies available across the UK, participants were fundamentally uncomfortable with inequalities in access. The urban engaged group speculated that rural areas would suffer due to lack of access to services, but urban early adopters would pay higher prices for technologies that would later be rolled out nationally. The rural engaged groups held more pragmatic views of urban-rural differences, drawing parallels with existing problems of access to high-speed broadband in remote areas. This group also suggested that those living in cities may be restricted too, for example, using a washing machine at off peak times may be limited due to potentially disturbing neighbours.

Although spatial variations in access concerned participants, they were more preoccupied by financial exclusion and the possible social repercussions. Participants could not see how those on lower incomes would be able to afford smart appliances, specialist services or an energy-efficient home. Participants envisaged energy as an increasingly scarce and costly resource: the well-off remain unaffected while the majority is left to cut back, worsening existing social divisions. Given that many technologies portrayed also appear to be quite advanced compared with those existing today, participants also envisaged that older generations would struggle to adapt enough in order to understand and benefit from such developments. Vulnerable people may become anxious and be taken advantage of by companies, or miss out on potential benefits.

The introduction of specialist companies offering services alongside power companies prompted concern over the degree of control they would have over consumers and access to personal data. Participants were wary of energy service firms, and this linked in to previous negative comments about the Big Six power companies. It was argued that the public would need to know the criteria by which they would operate:

> *'...it needs to be embedded in law so that [the local area] can't suddenly be switched off with power simply just so [neighbouring town] can have a bit more [...] who is going to be in control?*
> *(R4, Rural B)*

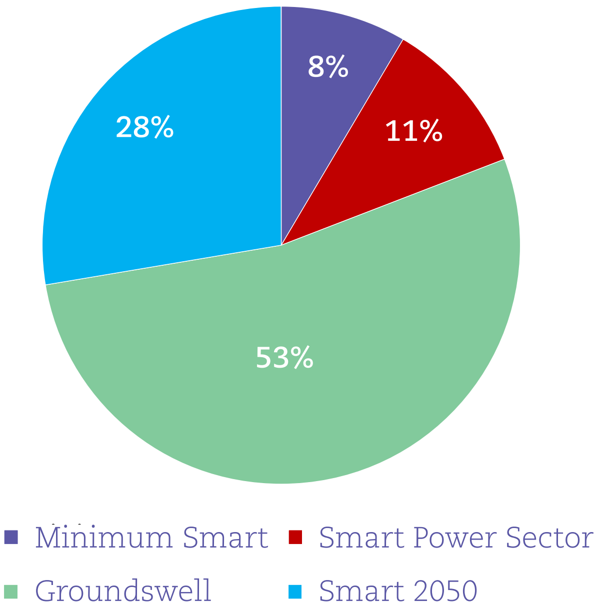
The Smart 2050 scenario was viewed as much farther in the future than the other scenarios, and as 'too much', 'too controlling' and 'confusing'. Automation of appliances was met with resistance as it was associated with a lack of control and an invasion of privacy:

> *'I don't want no company saying like 'well right about now your machine's not going to work because it's high peak [...] it's like it becomes to know your habits, it knows how you operate, that's kind of scary'*
> *(R1, Urban A)*

There was particular concern around fridges being automated, a fault occurring and food being spoiled. As systems increased in complexity, the chance of things going wrong increased too for participants. External controls would have to take into account people's varying needs (e.g. those with health problems). An override function would be essential, allowing consumers to take control if needed.

Real-time tariffs were seen as too complicated, with participants already confused about the current energy market and the multitude of tariffs on offer. Yet, some mentioned Economy-7 systems as simple, practical and something everyone could understand. Experience with energy tariffs was in direct

Figure 12. Public workshop participants' preferred scenario



contrast to people's experiences with mobile phone pricing which was more straightforward. Underlying all this was a lack of trust for institutions – insurance companies, banks, politicians – as well as the Big Six power companies.

This scenario also includes community energy schemes. The idea of communities producing their own energy was well received, seen as a way of regaining control and making money by selling excess energy back to National Grid. One rural group speculated over how urban areas would fare as it was assumed they might not be socially cohesive enough for the scheme to work. The rural engaged group, who had extensive experience of generating their own energy, had already had problems with the distribution of profits. Nevertheless, the idea of becoming more self-sufficient was appealing and represented a more old fashioned, sustainable way of life.

On the post-workshop questionnaire, participants indicated their preferred scenario. As shown in Figure 12, around half (53%) preferred the Groundswell scenario; the next most popular scenario was the Smart 2050 scenario, which was selected by 28% of participants. The reasons for choices made were also elicited (see Figure 13) participants could select reasons from a broader range provided). The most popular reasons were environmental and financial, particularly allowing for more renewable energy sources and reducing energy bills. Reasons relating to system operation, supply security and market structure were less popular. Rural respondents (61.1%) were particularly likely to select increased renewable supply as the reason for their scenario choice, compared to than urban respondents (38.9%). Those with smart grid-related experience (56.7%) were more likely to select 'being able to reduce your energy use' than were those without experience (43.3%), and to select 'many (new) companies providing smart home services' as a reason (72.7% vs. 27.3%).

Respondents were also asked about barriers that might stop your favourite scenario from becoming reality (again participants were able to select reasons from a broader range provided).

Figure 14 shows that the three barriers cited most frequently were: insufficient data protection measures, consumer unwillingness to share data, and insufficient financial savings for consumers.

Further observations

The last part of discussions aimed to reveal public views on key trade-offs that are likely to shape the functions and capabilities enabled by smart grids (Box 6). The first such trade-off addressed the sharing of individuals' energy use data in comparison with potential cost savings (i.e. the desire to protect privacy vs. the desire to reduce bills). The second examined the importance of renewable energy as opposed to the any-time availability of electricity at the same price. Regarding the first, participants wanted to see a more dynamic relationship where, if consumers shared information, they would be kept informed as to how it was used and what effective change it resulted in, as well as any gains or limitations observed over time. Some others argued that receiving financial benefits (i.e. reduced bills) in return would be a factor in their decision.

Box 6. Exploration of trade-offs in the public workshops

Privacy vs. Cost Savings: To keep your bills down, the companies that operate the networks (NOT power companies – although they may need this information in future) would like to know more about the way you use energy. We do not have to share this information but if we do, it will help to keep our bills down.

Clean Electricity vs. Any-Time Use: As we have more wind turbines to generate clean electricity, we may have to fit some of our electricity use into the time when most wind is blowing. This may mean using things like washing machines, tumble dryers and dishwashers when our smart meters say it's okay to run them.

> *'I think I would probably sit somewhere in the middle actually, I think I'd be reasonably comfortable with some information being made available and the trade-off being that I would get some kind of reduced cost'*
> *(R1, Rural Eng B)*

For some others, the decisive factor was whether they would receive clear benefit in return for sharing their data (via a 'derived' service [22], for example being able to monitor elderly relatives' wellbeing), building on 'motivated cognition' theory [23].

In the case of the second trade-off, it is interesting to note that for some participants having lots of renewable electricity in the system was regarded as a desirable 'end goal' and that they had very little understanding of the implications of this at a system level.

Whilst many participants recognised the environmental benefits of renewable electricity, they did not want to be restricted in their energy use, as their daily routine may be unpredictable.

Participants also discussed the reliability of advanced communication systems, especially in the context of physical geography. Based on past experiences, there were comments on how physical geography might limit the capacity of transmitters and what would it mean for the reliability of energy supplies. In addition, over-reliance on electricity was also raised, with concerns emerging over whether this would reduce security of supply.

A final observation relates to trust and perception of power companies. Mistrust towards power companies was more common in non-engaged communities than in engaged ones. Participants in one group, engaged in an active community scheme, explained how they have managed to keep their energy bills the same in recent years despite increases in the price of energy. Rather than appearing resentful, they discussed these issues much more neutrally, which may reflect a feeling of empowerment regarding their energy use.

Figure 13. Reasons for preferred scenario (% of participants)

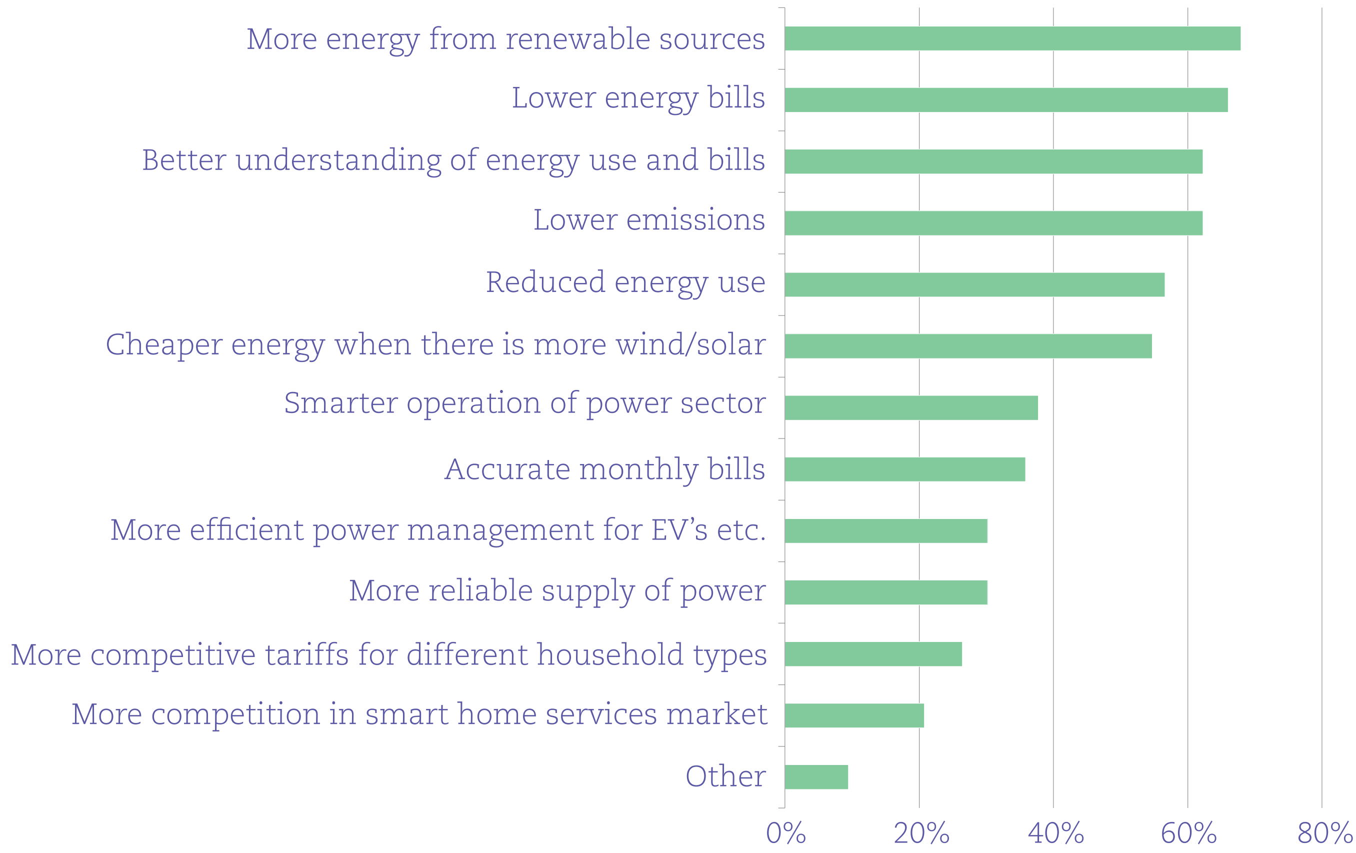
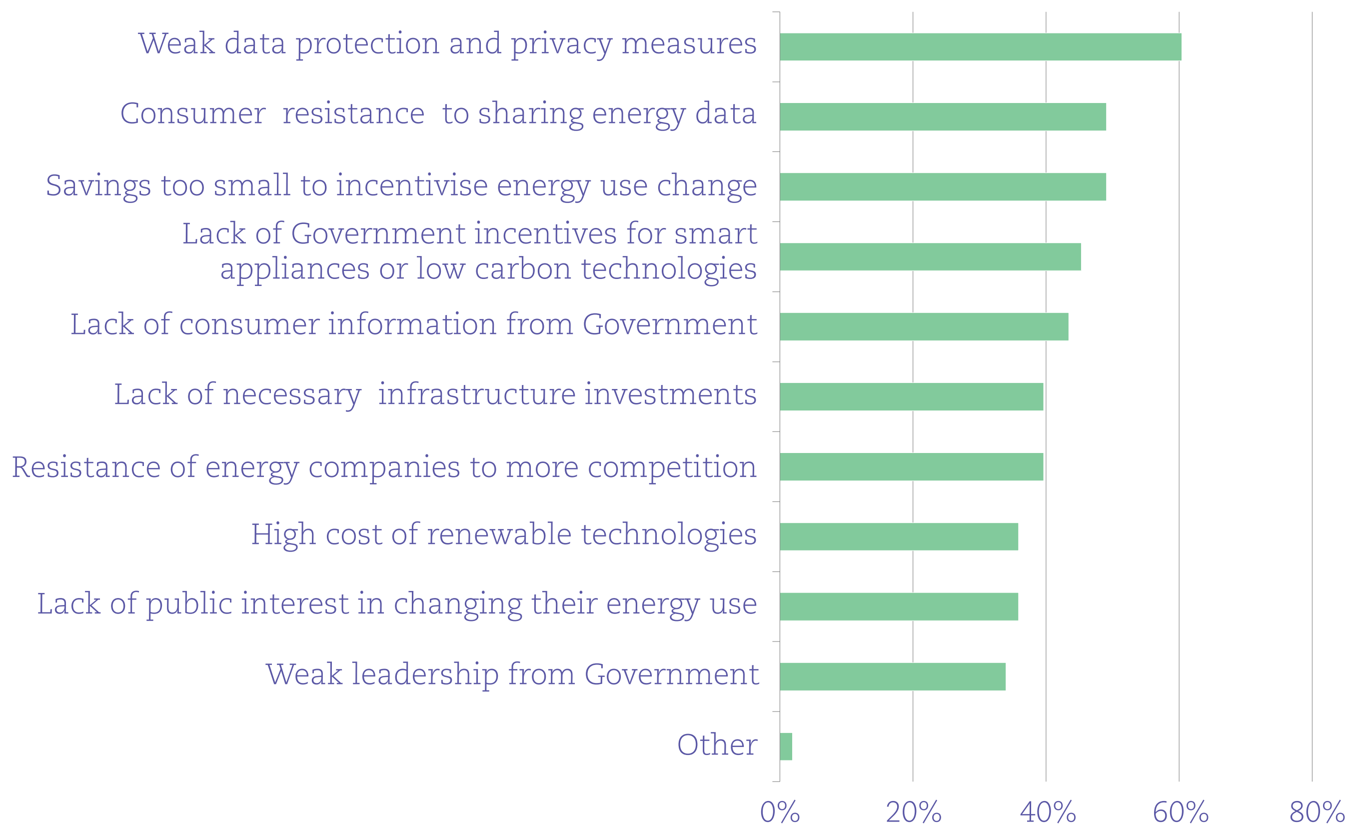


Figure 14. Perceived barriers to realising preferred scenario (% of participants)

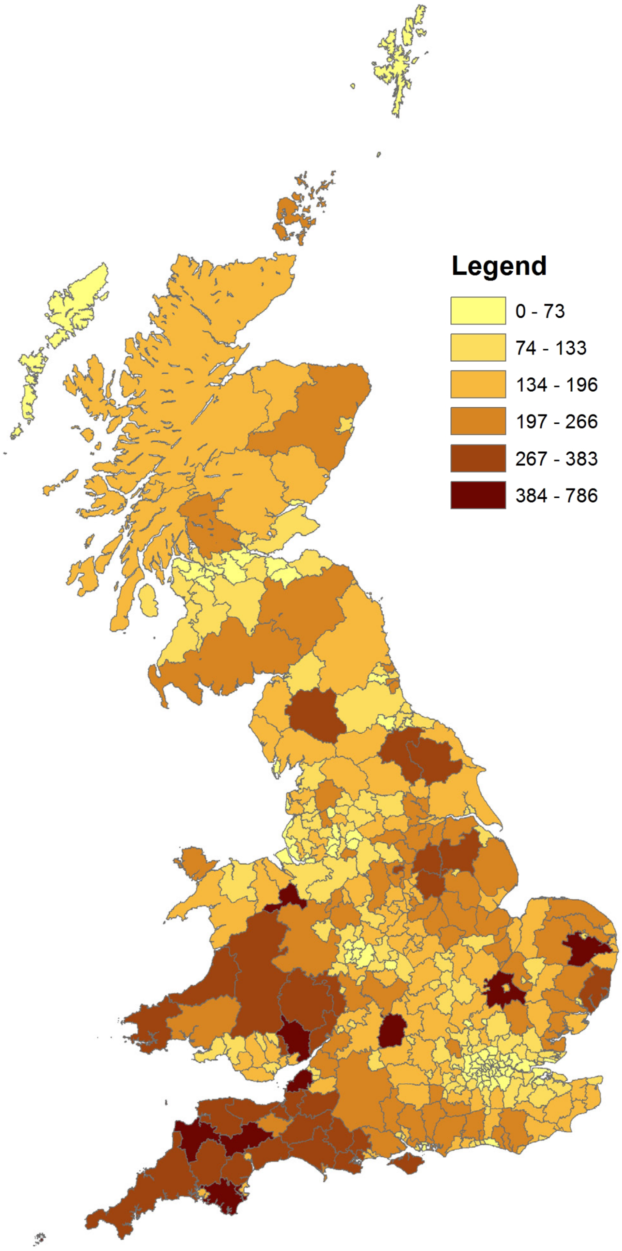


4.2 Spatial Implications

Our scenarios portray alternative pathways into future where new types of electricity demand (via electrification of heat and transport) and sources of supply (via distributed generation, including PV) are integrated into to the UK electricity networks. This presents multiple interdependencies: on the one hand policy incentives, market forces and consumer appetite are likely to determine where, at what speed and to what degree LCTs will be deployed. In turn, the net loads (i.e. the difference between consumption and generation sources) at the distribution networks will be different because it is unlikely that the same supply and demand sources will be deployed uniformly across the country. For example, whilst ground-source heat pumps may appear in rural areas off the gas grid, EVs may emerge in semi-urban areas, perhaps initially as a second car. Furthermore, a key issue in the early stages of deployment is local clustering of these technologies, as was evidenced by the growth of PV installations (Figure 15).

These technologies have impacts, most significantly, in low voltage networks. If the load experienced on a network reaches its maximum rating, investment will be needed to release additional headroom. Smart solutions such as DSR can play a significant role in avoiding or deferring costly investment in upgrading substation capacity. In return for shifting the time they use some part of their electrical demand to another time consumers may have the opportunity to access lower energy tariffs. The corollary of this is that consumers who cannot shift their demand may pay higher tariffs for energy used in periods of high demand. Some consumers may be unwilling or unable to shift their consumption (an obvious example would be vulnerable consumers who require heating throughout the day) and thus may see price rises. Inability to shift energy demand might also be due to economic circumstances, for example not having the capital to access smart technologies. An emerging literature on social issues points to a further risk that the availability of smart grid technologies and services might be perceived exclusive

Figure 15. Number of domestic PV installations per 10,000 households by local authorities, as at end of June 2013



Source: Ofgem E-serve database (as of 30.06.2013)

Notes: 1) There are 14,496 domestic PV installations that have not been allocated to Local Authorities due to missing locational references. 2) For Scotland, areas are represented as Council Areas.

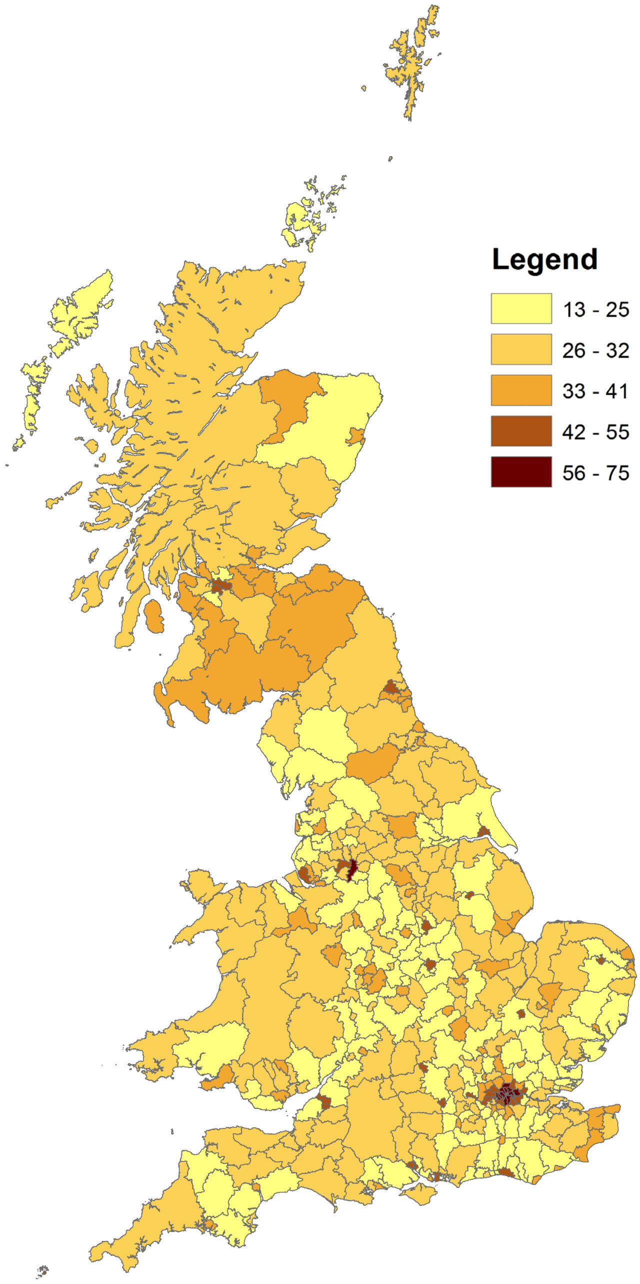
to homeowners only [24]. Indeed, an often-overlooked issue is that whilst 30% of the UK population lives in rented properties, in some areas tenants constitute up to three quarters of the population (see Figure 16).

Some consumers whose consumption patterns already fit the low demand profile may benefit but this would not deliver significant system benefits. The key uncertainty here regarding effectiveness is whether the different possible tariffs that might come to market can engender behaviour change, but there is also an issue as to the social impacts that might arise; will the adoption of new tariffs lead to more or less fuel poverty and associated impacts such as health? [25].

In addition to interactions between individual households and their ability to take up of the opportunities presented by DSR, other infrastructural, geographical, network and socio-structural characteristics might affect the spatial distribution of smart grid functions. Experts articulated that some smart energy system functions like DSR technologies, active load management and controllability are more likely to be in urban than rural areas. However, given a significant variation in energy use between urban and rural areas (Figure 17), including fuel source (or access to the gas grid), socio-economic variation and characteristics of the built environment, it is not known whether such factors can help or hinder the adoption of LCTs as well as how these technologies might affect these differences in the future. However, a guaranteed outcome is that deployment of LCTs will be layered on top of these disparities, resulting in a more spatially differentiated and diversified electricity system.

The literature on how urban and rural energy systems might be reshaped and reconstituted as a result of these changes in future is in its infancy and we have not had scope to explore these issues in detail. Key research questions include: at what level of variable generation does DSR become essential and would this vary depending on location (and if so, how)? What types of households are most responsive to DSR signals? How does the value of DSR change when it is used to address local congestion vs. national balancing?

Figure 16. Distribution of population living in rented housing (2011) (%)

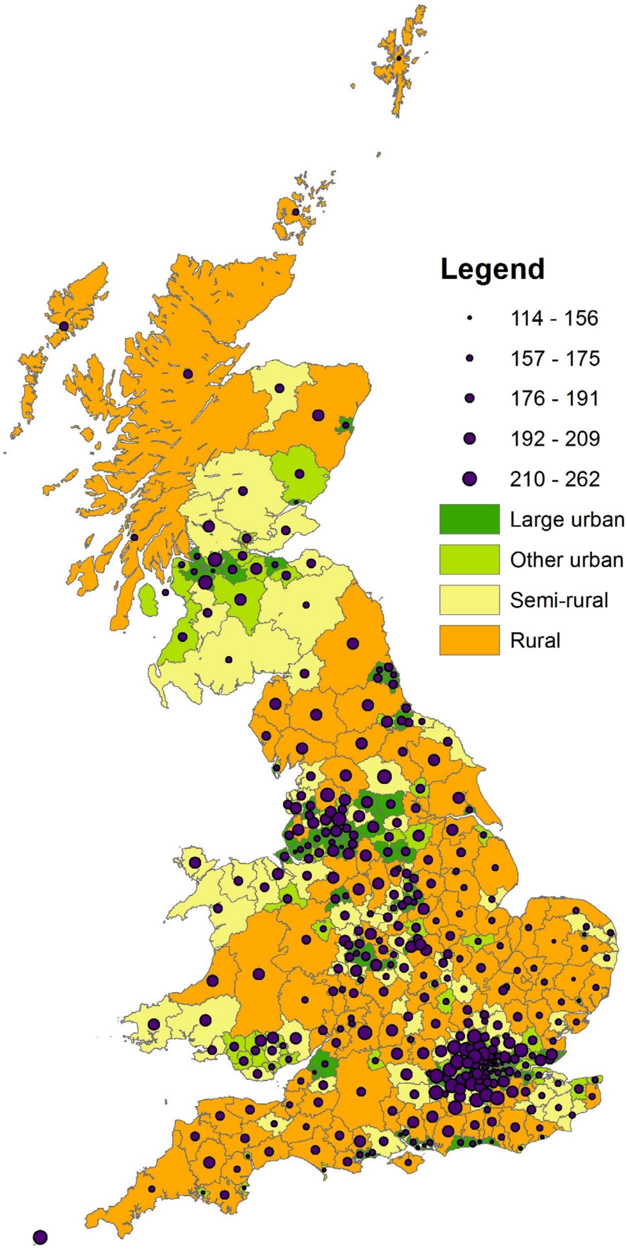


Source: Office for National Statistics (ONS) and National Records of Scotland (NRS)

What are the implications of controlling energy demand as well as supply and storage at a local level? What impacts might different EV battery-charging arrangements have upon electricity networks at both local and national levels?

There is limited research on the impact of LCTs on load growth and associated investment needs in the distribution networks [9], and so further research is needed. EA Technology (2012) assesses the impact of LCT uptake for prototype networks at extra high voltage, high voltage and low voltage levels for urban, suburban and rural areas. Whilst there is limited scope to anticipate how consumers will actually respond to these technologies and services (due to the 'action-value gap'), further research is needed to identify the nature and scope of this uncertainty, as well as how to utilise these differences to deliver effective, efficient and equitable outcomes rather than deepening existing inequalities.

Figure 17. Residential energy use per 10,000 households by local authorities by different geographies (2011, GWh) (%)



Source: Urban vs rural split is based on Office for National Statistics (ONS) and National Records of Scotland (NRS), Energy Data is based on [26]

Notes: For Scotland, areas are represented as Council Areas.

Discussion and Conclusions

5

The research reveals a high degree of uncertainty surrounding the future of smart grids in the UK. This applies not only to the general public, but also to those working in and with the industry, for whom stronger vision and leadership in the long-term would reduce risk, uncertainty and expense substantially. Some of this uncertainty might reasonably be expected to be mitigated by coordinated government action but some will require sectoral stakeholders to respond with new approaches to risk management and adopt new business models to address the 'broken value chain' problem. The need for government transparency and long-term predictability applies equally to drivers for a smart grid: solid commitment to renewable energy targets to 2030 and beyond, for example, is essential if the infrastructure of the future is to accommodate much more unpredictable and more decentralised power flows and the technologies needed to manage them.

The following section summarises key issues that will affect the direction and pace of smart grid development in the UK. Section 2 relates previous UK smart grid scenarios to ours. Section 3 focuses on the implications of our scenarios by identifying key messages for decision makers across government, industry and business.

5.1 Characterising determinants of smart grid development in the UK

Building on extensive stakeholder engagement via expert interviews, online surveys, expert workshop and public deliberative workshops, this project portrays alternative scenarios for the development of smart grids in the UK. Below we highlight a number of key issues that will determine which of these pathways might be realised in the coming decades in smartening the UK's electricity grid:

The benefits and pitfalls of smart grids. Although our surveys show that experts agreed on the need to make electrical delivery smarter, and that smart grids can afford various benefits – particularly cost savings, network balancing, facilitating renewables and emissions reduction – many also see smart grid solutions as unproven, underdeveloped, complex and difficult to implement. Consumer engagement and demand management were identified as benefits, but consumer resistance was also considered a risk. Data protection and privacy were identified as problematic, demanding greater transparency and data protection safeguards to gain customer trust.

Uncertainty. The development of smart grids involves many different elements within the electricity supply industry and the wider world. Action to reduce uncertainty would enhance the ability of all stakeholders to plan more effectively. We found that many stakeholders felt uncertainty over how the expected expansion of new energy technologies might shape networks, and that this makes it difficult for them to make definitive assessments, even over the next decade (relating directly to the 2015-2023 operating period of RIIO-ED1). No stakeholders felt able to evaluate future network needs or their evolution beyond 2025.

This throws up the question of how regulation would need to evolve alongside developing technology and market services. Experience suggests that it would have to take into account changing circumstances on an ongoing basis. Reducing uncertainty is not a straightforward matter. A national smart grid coordinator might have responsibility for identifying and shaping policy to mitigate risk. To be effective this would have to be able to influence policy at both Ofgem and DECC.

Risk Management. Since privatisation DNOs have existed in a regulatory framework that has rewarded gradual increases in efficiency with little incentive for innovation since it was seen as largely unnecessary. System-wide adoption of low carbon technologies is likely to change the demands on the networks and regulation has begun to change to reflect that. DNO behaviour will have to change with it, to invest in new technologies, strengthen their skills base, and make decisions based on developing networks which may need to handle integrated generation and increased and more volatile consumer demand – with limited information on when and by how much this might happen.

Coordination. As was also raised by the IET [28], overall coordination of activities is central to making sure smart grids happen and to ensuring potential conflict arising across the disparate elements of the electricity supply industry do not provide additional barriers to uptake. Concerns have been raised about a lack of vision in planning for smart grid development beyond 2020, with DECC singled out in particular as needing to provide more of a coherent lead.

Long-term policy. Predictable and sustained policy support is widely held to be essential for the deployment of LCTs, and it is likely that similar support for smart grids would create clearer investment conditions for the developers of the relevant technologies. Long-term policy commitment across the wider policy environment relevant to smart grids would be likely to contribute significantly to enhanced investor confidence. This is in relation to both the smart grid drivers (such as growth in renewables) as well as regulation to drive innovation and investment amongst network operators.

Organisational frameworks. The systematic rolling out of learning from Low Carbon Networks Fund projects (along with others) and their commercialisation will require proper incentivisation and the right investment conditions. Experts expressed concern around the capacity of DNOs both to invest in research initiatives and to roll out any innovative output from these programmes on a systematic basis. Since this is primarily an investment issue it may be necessary for DNOs to look for ways to do this and, at the same time, for Ofgem to give appropriate incentives which take into account any associated risk and benefits. Here as in other areas, the scope may be limited by what Ofgem will allow as much as the appetite of the DNOs to find new ways of doing things.

Markets. Finding ways of enabling new entrants and new services is essential. A market framework which allows new providers to offer new services more easily is likely to stimulate the kinds of innovation required for greater systemic smartness. This might include new supply companies, energy service companies, aggregators and DSOs depending on the evolution of the system and how investors respond. The current market is dominated by the Big Six, which has led to problems including market illiquidity and other disincentives to new entrants to the sector. Additional barriers to market entry by new small companies may include economies of scale, network charges, low sectoral margins and the complexity of regulation. The UK's ongoing Electricity Market Reform expresses concern and a desire for action to address this but questions have been raised around whether EMR as currently proposed will be successful.

Public acceptability. The public is ambivalent about smart grids, perceiving them to afford both benefits and risks. The most popular scenario was Groundswell, followed by the Smart 2050 scenario, with reasons relating to the environmental and financial benefits (e.g. more renewables, lower bills). Participants were able to envisage modifying their behaviour in order to use electricity from renewable sources, but with the proviso that they could override the system when necessary. However, in contrast there was a common view that the decision should be taken out of consumers' hands as part of a government-led green strategy.

Consumer data access. Smart meters will generate large volumes of data. The usefulness of this data in allowing better network management will depend on who has access to it, how long access is able to continue after the data is generated and whether it is geographically specific. At the same time there are significant concerns over the protection of data, its security and over consumer rights to privacy, confirming findings in the wider literature. Current negative perceptions of the Big Six power companies greatly influenced participants' attitudes towards data sharing (and to personal energy-related behavioural change). On the other hand, a Eurobarometer survey from 2011 indicates that two thirds of the UK population is unaware of the existence of a national public authority responsible for protecting their personal data rights [29]. Hence, there is a risk of both the exploitation of uninformed consumers who unintentionally give away more information than they are aware of, and for the imposition of unnecessary limits on accessing data from willing consumers. Again, communicating the benefits of data access to the public, ideally via a source perceived as neutral, is likely to have substantial long-term system benefits, particularly if this process is transparent.

Consumer buy-in. Securing public commitment, although challenging, is perceived by virtually all stakeholders as essential to opening up network services able to respond to a future system with substantial intermittent generation and increasingly volatile load. Rather than just 'flicking a switch' it is expected that the public will be able to choose from more differentiated and dynamic tariffs, become accustomed to operating new technologies and shifting their energy use. Whilst incentives may play a role, the communication of why these changes are needed and the role of power companies in this transition is equally important. Our research suggests that early communication of the benefits of smart grid capabilities, the establishment of effective delivery mechanisms (especially for the demand response market) and finding ways of ensuring that benefits flow to consumers are all likely to play a part in encouraging household participation.

Energy citizenship. Community energy may help to foster energy citizenship. Our public workshops revealed more positive attitudes towards functions and services offered by smart grids in communities with active energy schemes. These can play an important part in communicating smart grids benefits as well as addressing issues around mistrust towards power companies and government by fostering energy citizenship and empowering local communities.

Value proposition for consumers. Synergies with other smart systems may help to build a stronger case for smart grids in the eyes of consumers. For the majority of the UK population 'disclosing personal information is an increasing part of modern life'; 65% of UK citizens are aware of the need to disclose personal information so they can access new products or services [29]. Our workshop findings also support the view that if householders' data is used to deliver a service that contributes to their quality of life (e.g. being able to monitor their elderly relatives), they are more likely to share it. The development of joined-up thinking across policy areas as well as integrated services across energy, transport and healthcare domains, could not only generate cross-cutting efficiencies but might help alleviate consumer concerns on data privacy. An implication might be that this approach could be applied across different scales, from smart homes to smart communities and cities.

Distribution of costs and benefits. Moving from a system where the cost of delivering each additional unit of electricity is averaged across all consumers to one that reflects actual costs could have important social implications. It has been observed that this might lead to different electricity prices even on neighbouring streets, depending on the constraints on the grid at a given time [30]. It is vital that the costs are not perceived by the public to be unevenly spread, and the same applies to the benefits: many members of the public we spoke to felt that future changes would be designed simply to maximise power company profits. There are of course competing notions of what constitutes an appropriate distribution of costs, and adding these costs to bills may well be at odds with the objectives of fuel poverty campaigners. However, a perception that the costs of developing a smart grid are being borne inequitably would undoubtedly hinder the process.

Spatial differences. Experts articulated that smart energy system functions like DSR technologies, active load management and controllability would be more likely to be implemented in urban than non-urban areas, compounding current physical, socio-structural and infrastructural differences. There is a need for a better understanding of the two-way relationship between these inequalities and the uptake of various smart technologies and services. In order to avoid the widening of these differences, more research is needed to address how smart energy delivery would shape these differences and vice versa.

More research is needed so as to understand fully where and how the distributional impacts of smarter energy delivery are likely to fall, and how policy intervention could be used to avoid exacerbating existing inequalities.

5.2 Relevance to other UK smart grid scenarios

Building on the Carbon Plan's [6] examination of the uptake of LCTs at a national level, the Smart Grid Forum developed scenarios [9] on smart grid development in the UK, along with an associated modelling tool to assist DNOs in the preparation of their business plans for RIIO-ED1. Based on 2012 data, each of these scenarios assumes different levels of LCT uptake and DSR. Generation profiles follow the National Grid scenarios [6] where Scenarios 0, 1 and 2 are aligned with the 'Gone Green' scenario whilst Scenario 3 adheres to less ambitious decarbonisation of supply as portrayed in 'Slow Progression'.

Scenario 3 is most consistent with the Minimum Smart scenario in this report, where existing inertia in the system and a lack of strong policy incentives for decarbonisation, coupled with less interest from public, results in renewable energy and climate targets being missed and the need to purchase international carbon credits (see Table 3 on page 60). Scenario 0 draws the upper boundary as portrayed in our Smart 2050 scenario. Scenarios 1 and 2 have the same level of LCT uptake but different levels of customer engagement with DSR (lower in the latter). This therefore places them in the same areas as the Groundswell and Smart Power Sector scenarios respectively.

Our work builds on these ENA scenarios, but there is scope to explore the quantitative aspects in more detail. By drawing on existing literature and expert knowledge, consistent with overall framework of these scenarios, our scenarios indicate how interactions across policy, regulatory, commercial, financial, behavioural, organisational and technical factors might lead to one scenario versus another one. It is expected that the socio-technical framework we have adopted in our scenarios will help with the understanding of implications of key decisions for the decision-makers (whether in policy, industry or business) to avoid any unintended consequences, given the significant costs and benefits of smart grid technologies and the challenges ahead.

5.3 Key messages

This section contains a small number of key messages that have emerged from this research and the construction of the accompanying scenarios. These messages could either form the foundations of future research, or be addressed by various stakeholder groups or policymakers. Smart grids in the UK are currently at such an early stage in their evolution that a wide range of developmental pathways is available. A corollary of this uncertainty, however, is the opportunity that exists for shaping the direction the industry takes.

The need to develop a set of indicators in order to measure progress. The range of scenarios described in this report demonstrates that diverse outcomes are credible. These would be expected to have very different consequences for the achievement of government policy goals with regard to decarbonisation, security of supply and affordability. Furthermore, examining the 'wildcard' impacts reveals that there could be critical 'branching points' on the scenario pathways that may result in what was previously a satisfactory pathway flipping to an unsatisfactory one. The multi-faceted interdependencies between supply chains, consumer engagement, time lags between investment decisions and build-up of infrastructure etc. raises the need to have a sufficient vision to know whether we are following a pathway consistent with our goals.

Ensuring equitable outcomes. Smarter energy delivery promises to enable more efficient use of energy infrastructure through the introduction of differentiated tariffs and demand side response programmes. However, our research reveals that the distribution of benefits is unlikely to be uniform within and across different geographical settings.

Due to differences in lifestyles, socio-economic characteristics, education levels and normative constraints, consumers' ability and willingness to accept smart technology and services might vary within the same geographical settings. On the other hand, different smart grid functions and capabilities (albeit at different costs) might be enabled in different geographical settings as a result of physical, socio-structural and infrastructural differences. The development of business models, policy tools and measures to manage these differences, rather than widen them, is an important area for further research, as public perceptions here can act as a strong driver or barrier (see below).

Public engagement. Public workshop participants perceived more of the benefits from smart grids accruing to private companies, with more risks and/or costs accruing to consumers and society – that is, power companies, not 'ordinary people', will be the ones to benefit from smart technologies. Although we found that the public does generally see the lifestyle benefits of smart technologies, it is critical to build trust and repair the widespread negative perception of the industry so that lacklustre public opinion – or even outright opposition – does not impede smart grid progress. Our results also highlight the importance of community energy schemes for engaging the public with a smart grid transition: first, communities with an active energy scheme expressed less resentment towards power companies; secondly the scenario which had the most public support was Groundswell where strong community engagement is the key characteristic. This highlights the importance of building public trust in a way in which consumers do not feel they bear the risks and/or costs whilst not receiving the benefits.

Joined-up thinking across smart systems to generate consumer buy-in. The utilisation of opportunities and benefits offered via 'smart energy' delivery requires a shift from the traditional 'supply and predict' paradigm for both consumers and energy providers. Both our research and the emerging literature indicate that in order for consumers to share their data, there needs to be clear and demonstrable benefits of doing so. Whilst lower bills may motivate some, others would like to see how doing so contributes to their daily lives beyond limited financial savings (e.g. being able to monitor elderly parent's health from smart metering data). Hence, a way to initiate consumer buy-in and interest could be via offering integrated services within energy, transport or healthcare domains. Such an approach would require new working relationships and business models across the energy industry, business, information and communications technology (ICT) companies and other new entrants. Expert interviews revealed that the current advisory body, the Smart Grid Forum, is a good starting point, but that more needs to be done; for example, the development of a regulatory architecture that removes and addresses systemic barriers, and the addition of consumer representation in the Forum itself. Further research could be carried out to further the understanding of how smart grids can form the foundations of wider smart systems, such as smart communities and cities.

Risk, Innovation and Investment. Network operators are historically risk-averse, aiming to provide a highly reliable service with little scope or incentive for innovation. The emerging challenges to the electricity system will require different behaviour, with innovation coming to the fore to allow minimisation of costs. This implies greater risk and network operators will need to be sufficiently incentivised to take risks and innovate, in so doing generating learning effects. This in turn should reduce associated investment risks, which will need to be mitigated as far as possible to keep overall costs down. Risk aversion was seen as the single most important barrier to smart technology investments. Uncertainty over return on investment, particularly when caused by ambiguous government signals and regulatory instability, heightens investment risk and pushes up the cost of large infrastructure projects. A risk management approach therefore needs to be adopted across the whole range of actors, including government. Changes in culture are not limited to the network operators.

The potential for limitations from regulation was also noted; the regulator will need to be open to and willing to allow network operators to run greater risks.

Identifying no-regrets technology solutions could help to mitigate uncertainty. The possibility of very diverse futures raises the question of whether or not there could be some no-regrets technology solutions that can help to manage less-ideal situations. The Smart Power Sector scenario shows that balancing the grid may become more difficult in the absence of widespread demand side response. Bearing in mind the long lead times of infrastructure investments in the power sector, technologies like distributed storage or smart charging could be used as a part of a mitigation strategy. Further work needs to be undertaken in this area to identify such technology solutions and develop ways to support their commercialisation.

References

[1] Clastres, C. (2011). Smart grids: another step towards competition, energy security and climate change objectives. Energy Policy 39(9): 5399-5408.
[2] Smart Grids European Technology Platform (2011) http://www.smartgrids.eu/. European Commission, Brussels.
[3] Wack, P. (1985) Scenarios: unchartered waters ahead, Harvard Business Review, September-October 1985, 73-89.
[4] Hughes, N., Strachan, N., 2010. Methodological review of UK and international low carbon scenarios. Energy Policy 38, 6056-6065.
[5] D. Xenias, C. Axon, N. Balta-Ozkan, L. Cipcigan, P. M. Connor, R. Davidson, A. Spence, G. Taylor, and L. Whitmarsh (2014) Scenarios for the Development of Smart Grids in the UK: Literature Review, Working Paper, January 2014: REF UKERC/WP/ES/2014/001. http://www.ukerc.ac.uk/support/tiki-download_file.php?fileId=3510. UK Energy Research Centre (UKERC), London.
[6] DECC (2011) The Carbon Plan: Delivering our low carbon future. Department of Energy and Climate Change, London.
[7] National Grid (2013) UK Future Energy Scenarios, UK gas and electricity transmission. http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Future-Energy-Scenarios/. National Grid, London.
[8] Committee on Climate Change (2008) Building a low-carbon economy. The Stationery Office, London.
[9] EA Technology (2012) Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks, 31st July 2012, Prepared for: Energy Networks Association on behalf of Smart Grids Forum – Work Stream 3, available at https://www.ofgem.gov.uk/sites/default/files/docs/2012/08/ws3-ph2-report.pdf. Office of Gas and Electricity Market, London.
[10] Foxon, T.J., Pearson, P.J., Araposthathis, S., Carlsson-Hyslop, A. and Thornton, J. (2013). Branching points for transition pathways: assessing responses of actors to challenges on pathways to a low carbon future. Energy Policy, 52, 146-158.
[11] Mander, S.L. *et al.* (2008) The Tyndall decarbonisation scenarios, Energy Policy, 36, 3754-63.
[12] Elders, I. *et al.* (2006) Electricity Network Scenarios for GB in 2050. Supergen Future Network Technologies Paper.
[13] UKERC (2009) The UKERC Energy 2050 Project- Making the transition to a secure and low-carbon energy system. UK Energy Research Centre (UKERC), London.
[14] For socio-technical scenarios for the Dutch electricity sector see: Verbong, G. & Geels, F. (2010) Exploring sustainability transitions in the electricity sector with socio-technical pathways. Technological Forecasting &Social Change, 77, 1214-21.
[15] Gordon, T.J. (1994). The Delphi Method, AC/UNU Millennium, Project Futures Research
[16] Georghiou, L. (1996). The UK Technology foresight programme. Futures, 28, 359-377.
[17] Stevenson, V. (2011). Sustainable Hydrogen Delphi Survey Round 1 – Participant Report. H-delivery SuperGen project. http://www.st- andrews.ac.uk/media/Delivery%20of%20Sustainable%20Hydrogen%20Delphi%20Survey%20-%20Round%201%20Data%20Summary.pdf.
[18] Coyle, R.G., Crawshay, R. & Sutton, L. (1994). Futures assessment by Field Anomaly Relaxation: a review and appraisal. Futures. 26(1), 25-43.
[19] Gifford, R. (2011). The dragons of inaction: Psychological barriers that limit climate change mitigation and adaptation. American Psychologist, 66 (4), 290-302.
[20] National Grid (2013). Demand Side Balancing Reserve. National Grid, London.
[21] National Grid (2013). Supplemental Balancing Reserve. National Grid, London.
[22] Balta-Ozkan N, Davidson R, Bicket M, Whitmarsh L. The development of smart homes market in the UK. Energy. 2013;60(0):361-72.
[23] Bolderdijk JW, Steg L, Postmes T. Fostering support for work floor energy conservation policies: Accounting for privacy concerns. Journal of Organizational Behavior. 2013; 34(2):195-210.
[24] Balta-Ozkan, N., Davidson, R., Bicket, M. & Whitmarsh, L. (2013). Social barriers to the adoption of smart homes. Energy Policy, 63, 363-374.
[25] Owen, G. and J. Ward (2011). Smart Tariffs and Household Demand Response for Great Britain. Sustainability First, London.
[26] Balta-Ozkan, N., Watson, T., Connor, P.M., Axon, C.J. (2014) UK's transition to a smarter energy system: Contextualising spatial differences and their implications, AAG Conference, April 8-12, 2014, Florida, USA.

[27] DECC (2011) Sub-national Energy Consumption Statistics. Department of Energy and Climate Change, London.
[28] The IET (2013) 'Electricity Networks: handling a shock to the system'. The IET, London.
[29] European Commission. The special Eurobarometer survey n°359 "Attitudes on Data Protection and Electronic Identity in the European Union" (June 2011), http://ec.europa.eu/public_opinion/archives/ebs/ebs_359_en.pdf. European Commission, Brussels.
[30] Hardy, J. (2011) Workshop report: Policy, regulatory and social aspects of smart grids and applications, UK Energy Research Centre and EG&S KTN, 13-14th December 2011, Royal Society, London.

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