Scenarios for the Development of Smart Grids in the UK: Literature Review

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ICT	Information and Communications Technologies
SGF	Smart Grid Forum
ENSG	Electricity Networks Strategy Group
LCNF	Low Carbon Networks Fund
ESI	Electricity Supply Industry

RO	Renewables Obligation
RES–E	Renewable Energy Sources of Electricity
RHI	Renewable Heat Incentive
SG	Smart Grid
DPCR	Distribution Price Control Review
EMR	Electricity Market Reform
RIIO	Revenue = Incentives + Innovation + Outputs

Executive Summary

Smart grids are expected to play a central role in any transition to a low-carbon energy future, and much research is currently underway on practically every area of smart grids. However, it is evident that even basic aspects such as theoretical and operational definitions, are yet to be agreed upon and be clearly defined. Some aspects (efficient management of supply, including intermittent supply, two-way communication between the producer and user of electricity, use of IT technology to respond to and manage demand, and ensuring safe and secure electricity distribution) are more commonly accepted than others (such as smart meters) in defining what comprises a smart grid.

It is clear that smart grid developments enjoy political and financial support both at UK and EU levels, and from the majority of related industries. The reasons for this vary and include the hope that smart grids will facilitate the achievement of carbon reduction targets, create new employment opportunities, and reduce costs relevant to energy generation (fewer power stations) and distribution (fewer losses and better stability). However, smart grid development depends on additional factors, beyond the energy industry. These relate to issues of public acceptability of relevant technologies and associated risks (e.g. data safety, privacy, cyber security), pricing, competition, and regulation; implying the involvement of a wide range of players such as the industry, regulators and consumers.

The above constitute a complex set of variables and actors, and interactions between them. In order to best explore ways of possible deployment of smart grids, the use of scenarios is most adequate, as they can incorporate several parameters and variables into a coherent storyline. Scenarios have been previously used in the context of smart grids, but have traditionally focused on factors such as economic growth or policy evolution. Important additional socio-technical aspects of smart grids emerge from the literature review in this report and therefore need to be incorporated in our scenarios. These can be grouped into four (interlinked) main categories: supply side aspects, demand side aspects, policy and regulation, and technical aspects. A brief overview of each is provided below.

Supply

In terms of financing, smart grid investment requires a financial model that is different from traditional utility capital investment analysis, as a variety of technologies and programmes is required, none of which by themselves provide a business case but together yields the utility's required return. Benefits to the economy include improved network functionality and enabling the decarbonisation of UK energy generation. New players have been identified (large-scale renewable energy generation, distributed energy generation, storage infrastructure, small-scale generator manufacturers and ICT solution providers) in addition to the traditional players (large-scale power generators, transmission, distribution, electricity retailers). Storage (esp. small to medium size) has the potential to attract prosumers' attention and therefore enable virtual power plants (whereby several small-scale generators can be remotely controlled and monitored, similar to a large-scale power plant), reducing the need to integrate a large number of nodes to the grids. Decarbonisation of heat and transport sectors will require network reinforcements to enable it to deal with increased demand. Demand shifting is one – partial – mitigation solution, with smart meters providing some potential in this direction.

Demand

Apart from strengthening the supply side and infrastructure, consumer engagement plays a vital role in energy balancing, via demand reduction. Engagement, in turn, can vary greatly depending on the extent of understanding of and insights into consumer behaviour. While consumers do not always find it easy to relate energy consumption to everyday life, it appears that most of everyday energy use behaviour is not financially driven. Therefore the use of financially focused policies may only achieve limited behaviour change, compared to the untapped potential of other approaches. Generally, demand-relevant measures can be classed into energy efficiency (involving one-off purchase of energy efficient equipment, insulation, etc.) and energy curtailment (involving regular habit change to reduce energy consumption, such as less cooking, turning off unused lights, etc.) measures. These two categories depend on very different factors and may therefore respond to different policies.

Public engagement with smart grid relevant technologies, given the right context and timing is another factor that can shape smart grid deployment. For smart meters in particular, the results of current and recent pilot schemes indicate that the outcome of first stages of implementation has a significant impact on how later stages evolve. Attitudes to smart homes vary greatly with demographic characteristics, and are most popular with younger consumers. Differential energy tariffs have not been successful, because of lack of awareness, “switching inertia”, practical issues, but also, importantly, because of lack of trust towards energy suppliers.

Electric vehicles are considered important accessories to smart grids owing to their storage potential and significant electricity consumption, assuming widespread adoption of electric mobility. Although attitudes are generally positive, current adoption rates are extremely low. Main reasons for this are financial, as well as lack of government support and infrastructure, and range anxiety. However, the rate of adoption of electric vehicles will help shape smart grid deployment, and pricing/subsidies appear to be essential for this process. Finally, micro-generation has great potential benefits for the grid, via the immediate contribution of energy but also by shaping demand and promoting energy citizenship. The latter is a much more promising approach than incentives and similar limited measures, signifying the importance of a decentralised system transition to low-carbon electricity with the associated benefits of distributed generation and active load management from the user. However associated costs seem to be a major barrier for the adoption of micro-generation even from motivated consumers.

Policy and regulation

The UK Government has adopted a number of policies which will drive growth in renewable energy, and is aware that this will require substantial investment in generating capacity and network infrastructure. Predictions about the long-term electrification of heat and transport further obviate the need to change both the physical system, as well as the market and investment incentives that drive its design and use. Achieving both long and short-term renewable energy generation and greenhouse gas emissions reductions targets will require substantial investment in generating capacity, grid infrastructure and energy efficiency. Simultaneously, the UK will need to maintain security of supply during a period when many large-scale generating plants are nearing the end of their lives, whilst meeting emissions legislation that narrows the range of new plants which can be built, contending with a grid that is better suited to centralised rather than distributed power generation and balancing a grid supplied by an increasing amount of intermittent renewable energy as mandated by environmental policy.

Achieving environmental and security policy goals, whilst reducing costs in the system and ensuring savings are passed to the consumer, will require changes to the way in which we regulate and incentivise generation, network operation and supply, as well as opening up options which change the way consumers consume energy.

The UK has begun rolling out smart meters and has initiated the process of reforming electricity sector regulation. This process will have stimulus of a smarter grid at its centre, though as yet there is considerable scope for what this will mean in terms of the technology that will be stimulated, the additional services that might be provided, the costs and benefits that will be engendered with selected stakeholders or the degree to which these will penetrate the sector. Innovation will need to play a substantial part in the reformed energy services industry but how to create the circumstances which allow this, while rewarding risk takers and without unnecessarily burdening consumers or undermining the economic competitiveness of British industry, will be a challenge for years to come.

Technical aspects

Information and communication technologies (ICT) are central to smart grids in order to manage bi-directional electricity flows, reliable grid operations, and security issues. On the latter point, SCADA (supervisory control and data acquisition) equipment is well-established and robust at the national level. However, remote equipment requires strict governance, as it comprises entry points for disruption. In terms of standards, an important prerequisite for the successful implementation of smart grids is the harmonisation of over 300 different operational and security standards. The common information model (CIM) is an evolving platform for the future deployment and integration of smart grids, offering greater reliance on renewable energy sources and the deregulation of increasingly interconnected electricity markets, and is promising to govern inter- and intra-operability within smart grids.

Situational awareness is another area of increasing need for attention, as it deals both with power and data flows. Cloud computing architecture may provide a solution here, provided that security concerns are adequately addressed. Synchronised Phasor Measurement Units (PMUs) are significant developments enabling wide-area monitoring and as such enabling important background features of smart grids. Recognising that wide-area monitoring and control are one of the key aspects of the smart grid, power utilities globally are predominantly starting to use PMUs to improve situational awareness through online stability monitoring.

Reliability of power systems operations has also been prioritised in recent years and the current requirements of online control systems (fast stability calculations, trace network analysis sequences, and reporting in a rapid decision enabling format) are demonstrated in two Japanese case studies. New applications in smart grids rely on vast networks of intelligent electronic devices that monitor the power system status and act in case of contingencies; this further emphasises the need for integration and optimisation of communication and security standards.

Cross cutting themes

We identified, as part of the present literature review, several themes cutting across most or all aspects of supply, demand, policy and technology. These consist of security of supply, cyber security, privacy, and control, system fragmentation, electric vehicles and heat important to smart grids, microgeneration and decentralisation, smart meters and distrust. These themes should not be considered exhaustive and others may emerge as a result of this project.

1 Introduction and context

1.1 Introduction and aim of this review

Smart electricity grids are widely considered an integral part of the transition to a low-carbon energy future. They currently enjoy a prominent place in the technology and energy literature and practice, and recently the UK government earmarked £500 million, via the Low Carbon Networks Fund (LCNF), for large-scale trials of technologies including smart grids. Yet, there is no currently accepted definition of what a smart grid actually is, with different working definitions across different working groups and countries. It is useful to note however, that widely accepted components of a smart grid (SG) appear to be efficient management of supply (including intermittent supply), two-way communication between the producer and user of electricity, and the use of IT technology to respond to and manage demand, and ensure safe and secure electricity distribution. The very lack of a clear definition points to the fluid and dynamic nature of this field, including susceptibility and uncertainties for its future deployment. In the past and in different, though comparable, energy industries, the use of scenarios has helped guide the response of relevant players. In the same spirit, this project aims to develop possible scenarios for the development of smart grids in the UK.

In this review we will attempt to cover the multitude of issues related to the inception, development and implementation of smart grids between now and 2050, and structure possible UK-focussed scenarios to help understand this process. We draw on a variety of academic and other sources (including industry and policy reports) identified through internet and bibliographic searches. In order to focus the extensive relevant literature, we organise this review into three parts. In the first part we aim to provide the current context in the electricity landscape in terms of market forces, policy, regulation, as well as identify existing scenarios for the development of smart grids. In the second part we take an in-depth look at supply and demand issues, policy, regulation and technical aspects as potential components in scenarios for the possible development of smart grids in the UK. In the third part, we examine cross-cutting themes in these scenarios, such as security of supply, data security and privacy, spatial variation and deployment capacity. On the basis of this review, we will then be able to develop specific scenarios which will further be refined with the help of relevant stakeholders. These refined scenarios will help inform decision-making and steer the process of smart grid development for the coming decades.

1.2 Smart Grids: Definitions

There is no currently accepted definition of what a smart grid actually is, with different working definitions across different working groups and countries (Clastres, 2011). The SmartGrids European Technology Platform (2011), for example, define smart grids 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’’. The IEC (2010a, p.6-8) state simply that “the Smart Grid is the concept of modernizing the electric grid [...] the main focus is on an increased observability and controllability of the power grid”. US definitions of smart grids focus more on energy system resilience and reliability (see Clastres, 2011). Smart grids are also defined in terms of a broader range of social, environmental and economic features and functions. For example, DECC (2009d, p.1) state that:

> “Building a ‘smarter’ grid is an incremental process of applying information and communications technologies (ICTs) to the electricity system, enabling more dynamic ‘real-time’ flows of information on the network and more interaction between suppliers and consumers. These technologies can help deliver electricity more efficiently and reliably from a more complex network of generation sources than the system does today. With a progressively smarter grid, operators get more detailed information about supply and demand, improving their ability to manage the system and shift demand to off-peak times. Consumers are offered far more information about, and control over, their electricity use, helping reduce overall demand and providing a tool for consumers to reduce cost and carbon emissions. Smart grids offer the prospect of delivering electricity in a low carbon future more efficiently and more reliably, intelligently integrating the actions of all participants in the system”.

Industry body EurElectric (2010) identifies the following desirable functionalities of smart grids:

a. Smart network management (conventional grid development combined with: faster fault identification and self-healing capabilities via grid automation; Advanced network operation and control; and smart metering)
b. Smart integrated generation (balancing power grid with large shared of renewables including distributed generation; integrating electric vehicles and heating and cooling systems; intelligent storage systems); and
c. Smart markets and customers (developing demand response programmes and load control; aggregating distributed energy sources including e-mobility).

Smart grids cover a range of upstream (generator), downstream (consumer) and network technologies, including smart meters (which measure energy consumption in real-time and can broadcast it to users and/or suppliers), sensors and communication networks (which transmit data on network performance in real-time; Clastres, 2011).

Areas of disagreement about smart grid definitions (or 'visions') include the scale at which they operate, i.e., decentralised supply systems to regional supergrids. Other areas of disagreement include the very components of smart grids, for example whether smart meters are necessary components thereof (ERGEC, 2010). It is worth noting that we can also contrast developed and developing countries' conceptions of SGs. From the perspective of a developing country, rather than developing the whole grid, SGs might offer more potential as 'just' grids (Bazilian *et al.*, 2011).

From the range of extant definitions, there are certain components which are broadly understood to characterise SGs. These include:

- efficient management of supply (including intermittent supply),
- two-way communication between the producer and user of electricity,
- use of IT technology to respond to and manage demand, and
- ensuring safe and secure electricity distribution.

This control of demand to match supply contrasts with current electricity networks which are characterised by control of supply to match demand.

The very lack of a clear definition points to the fluid and dynamic nature of this field, including susceptibility and uncertainties for its future deployment. For the purposes of this project, we will use these core defining features as a working definition, but through subsequent stages (notably the Delphi study) we will seek to further refine and clarify our understanding.

1.3 Smart Grids: Drivers, benefits, barriers and issues

UK and European policy interest in smart grid technologies is based on their potential to contribute to policy goals of a transition to a low-carbon economy, energy security and affordability by transforming the ways we produce, deliver and consume energy, and potentially our conception of these services. Smart grids are able to provide better planning and management of existing and future electricity distribution and transmission grids; actively manage supply and demand; and enable new energy services and energy efficiency improvements (ETPS, 2007).

Current research into these transformations (UKERC, 2009; DECC, 2009d; CCC, 2008) indicates a decarbonisation of energy supply, increasing distributed generation and potential electrification of transport and residential heating, potentially with demand side response strategies and storage technologies to help address intermittency and peak-load constraints, might all be managed more efficiently by SGs. In turn, this would help meet the UK target of an 80% reduction in CO_2 emissions by 2050, the European target of a 20% share of renewable energy sources by 2020, as well as addressing the need for infrastructure renewal, global leadership and competitiveness, and consumer concerns about affordability.

SGs feature in several energy and electricity scenarios (Robinson, 1990; Elders *et al.*, 2006; Mander *et al.*, 2008). However, the development of SGs goes beyond the electricity industry and will depend on other factors including: consumer concerns about data privacy/security and loss of control due to remote operation of appliances to manage peak load (Edison Electric Institute, 2010); development of pricing mechanisms and transition access management through regulation; provision of market and regulatory systems that will drive innovation and make innovation and investment in new services and technologies viable, and allow firms to seek competitive advantage (Baker *et al.*, 2009, 2010; Ofgem, 2011c) (addressing the so-called broken value chain in a deregulated electricity industry; Bialek and Taylor, 2010); as well as financing this new infrastructure and achieving a fair distribution of costs and benefits (Clastres, 2011). In part 2 of this review, we consider these issues in more detail, and in part 3 consider how scenarios might help expose and better understand the benefits and barriers.

Roadmaps are beginning to be developed to identify the sequence and duration of critical steps needed for a SG roll-out (e.g., IEC, 2010a; Table 1). EurElectric (2010), for example, identify a ten-year roadmap comprising: regulatory incentives for grid innovation, developing market models, setting standards and ensuring data protection/privacy, testing and demonstration, smart meter roll-out, monitoring and controlling the grid and distributed generation, moving to integrated local and central balancing of all generation, aggregating distributed energy sources, integrating large-scale e-mobility, heating, cooling and storage, and increasing customer participation in the power market. Clearly the wide-ranging actions needed for a SG roll-out imply responsibilities lie not only with policy-makers, but also with industry (electricity network operators, DSOs, energy suppliers, transport, ICT, etc.), regulators, consumers and others.

Barriers to SG deployment include technical issues (e.g., interoperability), regulatory issues (e.g., development of standards), as well as consumer concerns and behavioural issues (e.g., distrust in energy companies, energy consumption habits). Challenges also exist with respect to innovation within the current energy system, particularly in the context of historical regulation for cost reduction alone. Questions also remain about how SGs could facilitate functionality to offer incentives for individuals and communities to engage with renewables, district heating, and time of use tariffs. These issues are explored further in part 2 of this review.

Electricity Networks Strategy Group (ENSG) is a high-level forum acting as a smart grids focal point in the UK by bringing together network stakeholders to support Government in meeting the long-term energy challenges of tackling climate change and ensuring secure, clean and affordable energy. The Group is jointly chaired by the Department of Energy and Climate Change (DECC) and Office of Gas and Electricity Markets (Ofgem), and its broad aim is to identify and co-ordinate work to help address key strategic issues that affect the transition of electricity networks to a low-carbon future.

In February 2010 ENSG published *A Smart Grid Routemap* as a high-level description of the changes that need to occur to deliver the smart grid vision to contribute to the realization of Government carbon targets and end-customer benefits. ENSG suggested that is critical to deliver well-targeted pilot projects between 2010 and 2015.

In December 2009 Ofgem announced a funding mechanism of £500m, The Low Carbon Networks Fund (LCNF) (Ofgem, 2011c), over the period 2010 to 2015 to support "large-scale trials of advanced technology including smart grids". ENSG believes that the pilot projects create the right mix of technical, commercial, industry and regulatory change to overcome diverse challenges and will prove to be technically and economically successful. Coordination will be required to ensure that all pilot projects have a common and integrating goal. ENSG suggests that these pilot/demonstration projects will be available from 2015 onward for UK-wide application.

Policy integration, business case development, stakeholder management, knowledge and learning management and partnerships and funding are considered the delivery vehicles for 2010 to 2015. ENSG identified a number of outcomes such as develop regulatory and commercial arrangements, build industry capabilities and capacity, inform and involve customers and trial integrated technology at scale to be delivered by projects in short-term between 2010 and 2015 for preparing UK for large-scale applications (ENSG, 2010).

Across both the short-term (2010-2015) and long-term (2015-2050) the delivery of the *Smart Grid Routemap* (ENSG, 2010) depends on: ensuring a high degree of consideration across overlapping policy and the end to end energy value chain, getting customer on board as a key participant, adopting a set of common open standards and open access to drive a high degree of customer focused innovation, a think-big, start-small and scale-fast

approach, ensuring an ongoing engagement between Government (local and central), Ofgem, industry and customer representatives and finding a robust, thorough and embedded end to end security and data privacy solution with a degree of ongoing centralised management and enhancement.

Table 1.1: Electricity Networks Strategy Group's Smart Grid Routemap and Low Carbon Networks Fund

1.4 Existing scenario approaches

Purpose of existing scenarios

Traditional forecasting techniques have been replaced by the construction of scenarios in order to adapt, adequately describe and predict forthcoming environment challenges and evolving technologies (Wack, 1985). Constructing different scenarios allow qualitative and quantitative data to be combined in order to model and assess alternative possible futures. To date, some aspects of SGs have been included in wider electricity network scenarios, yet within these wider scenarios it has been acknowledged that there is little existing evidence on how to instigate change in people's lifestyle and behaviour (UKERC, 2009). A number of different methodologies have been utilised for scenario development, such as backcasting, extrapolation of high-level trends, formal modelling, technical feasibility, and narrative construction. It has also been suggested that the utility industry has established good technical ‘roadmaps’ for the SG, however there are calls for a social roadmap to understand customer experiences and how to engage them (Honebein *et al.*, 2011).

Fitness for our purpose

There have been varying levels of stakeholder engagement from the academic and wider stakeholder community in order to evaluate the various factors which will impact on future technological developments. Existing scenarios have focused upon macro-level factors, such as economic growth and the evolution of policy surrounding SGs (Edison Electric Institute, 2010); yet questions still remain, for example, regarding relationships between the utility industry and consumers. Industry refers to smart meters, distribution automation and dynamic pricing, yet customers relate to the subject in terms of affordability, reliability and control. While there is a broad understanding among those in the field of the benefits of SGs, it is important for future energy scenarios to incorporate environmental, social and economic factors. Nevertheless, our understanding of such complexities lags behind the potential capabilities of SG technology (Blumsack & Fernandez, 2012). Little work has been done investigating the roles and priorities of different actors, spatial variation and behavioural issues in relation to SGs. A recent study developed complex real world scenarios with multiple actors to demonstrate how small rural and peri-rural communities may adapt and respond to SG technology. In addition to the study’s focus on a particular type of community, a key limitation was the lack of consideration for spatial and temporal distribution of energy use and production (Trutnevyte *et al.*, 2011).

The little qualitative work conducted with the public on SGs suggests that around a third of participants had some prior knowledge of smart meters (Ofgem and FDS (2010); see also section 2.1). Further work is needed in this domain on the implications of deploying SG technology, in order to develop comprehensive and credible understanding of social issues. Early public engagement is critical to understand societal acceptance of ground breaking and potentially controversial technologies. The complexity of SG systems demands that the lessons learned from understanding the interaction of different actors be incorporated into the development of scenarios.

Consequently in this project we adopt an in-depth multi-disciplinary approach, incorporating the above dimensions, and including indicators identified as relevant by diverse stakeholder groups (consumers, network operators, producers, and regulators, energy service companies, ICT firms, etc.). We will examine how a particular cluster of technologies/services might evolve interlinked social systems and practices. This approach differs from many other recent scenario projects which focus on how a particular policy goal might be achieved. Our approach will combine elements of backcasting and forecasting, utilising both qualitative and quantitative methods throughout the study. We aim to add strategic value by taking into account specific system actors, their motivations, sense of control and the networks and relationships between them, and by revealing critical transition points and spatial differences within the UK energy system.

With regard to critical transition points, the ENSG has developed a UK SG routemap to 2050 which shows a single route of steps to SG development. However, no allowances are made to any barriers possibly encountered, or that steps to development may not occur in a linear order, and no consideration is given to stakeholder acceptability or lack thereof. Our scenarios will be developed on the assumption of a heterogeneous rather than homogenous energy system, accounting for differences in: (a) socio-economic demographics; (b) energy service demands, and (c) levels of end-user engagement with the energy system.

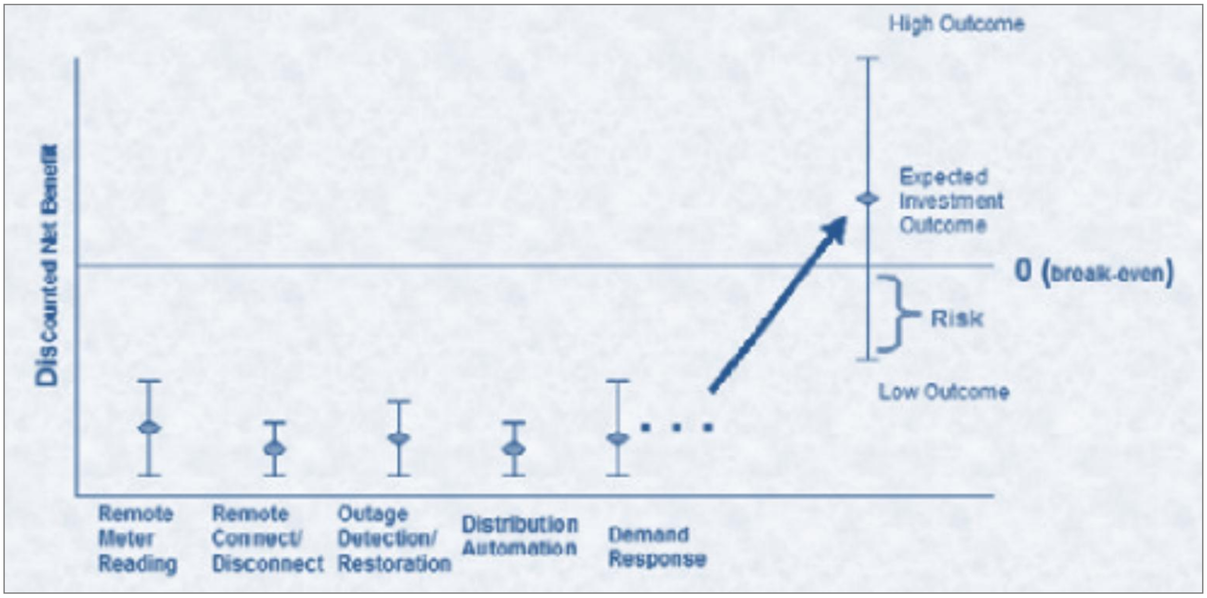
2. Scenarios components

We have identified four domains which contribute material to the development of scenarios. These domains focus on different aspects of the electricity grid, its components, management, function and people's relationship with it. Understanding these aspects, and the ways in which they can become "smarter" is at the heart of smartening the electricity grid. The four domains are: supply-side, demand-side, policy and technology. We now turn our attention to each of them in detail.

2.1 Supply-side aspects

Addressing the challenges associated with smart grids and realizing the opportunities they can provide depend on the operation and integration of the following foundational key technology areas: i) sensing and measurements, ii) advanced components, iii) advanced control schemes, iv) improved interfaces and decision support system, and v) integrated communications (Roy *et al.* 2011, p.67). However, the existing grid systems operate in liberalized markets where there are different actors for transmission, distribution and supply of electricity and the benefits these technologies can provide might sit with other parties. As a result, smart grid investment requires a financial model that is different from traditional utility capital investment analysis. This is mainly because a smart system requires a variety of technologies and programmes, none of which by themselves provide a business case but together yield the utility's required return (Jackson, 2011).

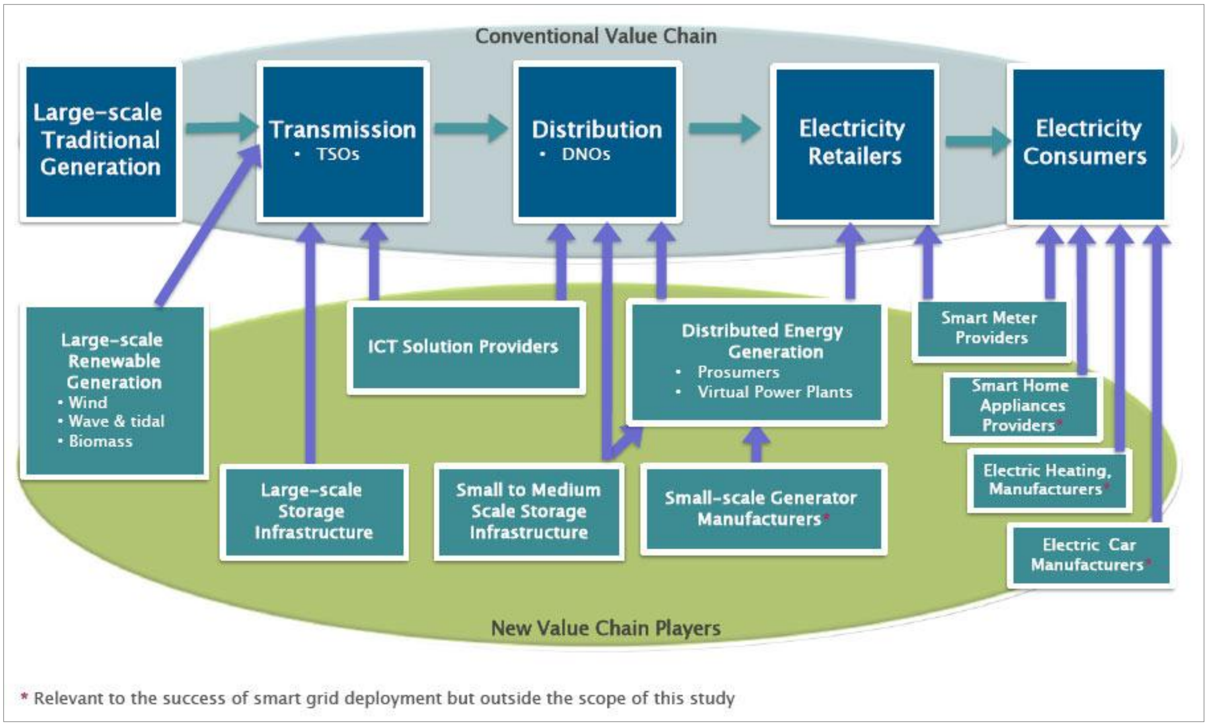
Figure 2.1: The smart grid investment problem



Source: Jackson (2011, p.77)

SG would add value to the economy by increasing and improving network functionality and preventing the need for substantial physical reinforcement of the networks, or indirectly by acting as an enabler of the decarbonisation of the UK electricity generation. EG&S KTN (2011) provides a detailed discussion of a UK smart grid vision with a focus on the identification of new industrial players and new relationships across the value chain. In the current system, there are five major players: large-scale power generators, transmission, distribution, electricity retailers and consumers. On the network side of the chain six new players are identified: large-scale renewable energy generation (i.e. wind, wave, tidal, biomass); distributed energy generation; (in order to deal with variability and uncertainty of these) large to medium and small-scale storage infrastructure; small-scale generator manufacturers and ICT solution providers. At the consumers' end, potential new players are electric car manufacturers; electric heating manufacturers; smart home appliances providers and smart meter providers. The location of these new players in comparison to the current electricity system is given in figure below:

Figure 2.2: UK smart grid vision with new players and relationships



Source: EG&S KTN (2011, p.16)

Large-scale energy storage would help with the grid's balancing operations. However, a more interesting concept is the small- to medium- scale energy storage which will help with managing the variability and uncertainty with distributed generation. With the introduction of real-time pricing mechanisms, energy storage solutions might attract attention from the prosumers who can sell their electricity when prices are higher.

Through so-called ‘virtual power plants’, a number of small-scale generators can be remotely controlled and collectively monitored (similar to a large-scale power plant), thereby reducing the challenges of integrating a large number of nodes to the grids. As a result, VPPs provide advantages both for the electricity grid operators and the prosumers: the former is due to cost savings via distribution optimization services while the latter arises through small producers gaining market visibility and optimising their electricity sales.

EG&S KTN (2011) however notes the importance of developing commercial and regulatory frameworks to enable the emergence of VPPs. Another issue relates to the limitations for the development of a commercial relationship between DNOs and VPPs as currently the former is prohibited from directly selling energy. How smart grids can generate value for each of the existing or future value chain players is summarised by EG&S KTN (2011).

Table 2.1: Value added across the smart grid value chain

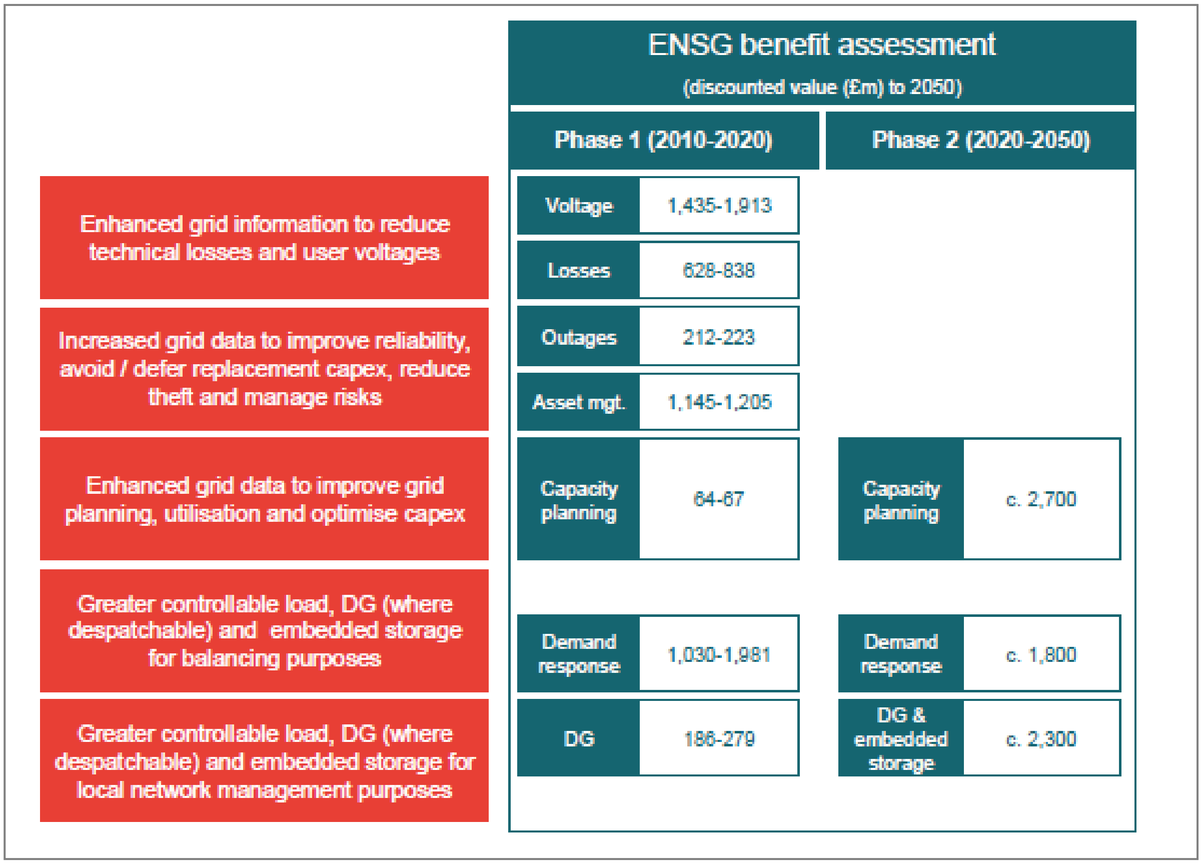
Smart Grid value from the perspective of industry incumbents			Smart Grid value from the perspective of new industry players (e.g. VPPs, technology providers, renewable energy producers)	Smart Grid value from the perspective of consumers and prosumers	Smart Grid value from the perspective of third parties
TSOs	DNOs	Electricity Retailers			
• The Smart Grid will provide a more flexible network to accommodate in a cost effective way the new inflexible and intermittent forms of generation to be added to the system in the upcoming decades. • Industry incumbents can also provide a network more capable of coping with physical outages and extreme events, by dynamically re-routing power and adjusting demand. • The Smart Grid can utilise network assets in a more efficient manner, due to their improved asset monitoring and sensing capabilities. This could enable significant savings by postponing reinforcement costs.			• For all potential new entrants, the Smart Grid represents a significant and sustainable business opportunity.	• Consumers will be able to directly participate in the electricity market. • Consumers will also become more and more attracted by the opportunity to become prosumers. Indeed the grid will be increasingly able to integrate in a cost effective manner the micro-inputs of electricity coming from local micro-generators (e.g. solar panels, small wind turbines etc.).	• Smart Grids will be able to accommodate high penetrations of electric vehicles and heating systems.

Source: EG&S KTN (2011, p.20)

A joint document by the regulator and the policy maker develops proposals for how smart metering will be delivered, including design requirements, central communications, data management and the approach to roll out (Ofgem and DECC (2010)). For the actual roll-out of smart meters, two options are discussed: i) full establishment and ii) staged implementation, DECC 2010). Under Option 1, the roll-out does not start until the central data and communications (DCC) systems are in place. Option 2 is a transitional arrangement option where the start of the roll-out precedes the full establishment of the DCC. DECC's impact assessment covers three types of costs: capital and installation costs (including capital, installation, and operational costs); communications costs and organizational costs (legal, setup, IT, disposal, energy and pavement reading inefficiency costs). The benefits for consumers are due to two types of change in average consumption behaviour: a reduction in overall energy consumption as a result of better information on costs and use of energy, and a shift of energy demand from peak times to off-peak times. These costs and benefits are defined over a 20-year period and against a counterfactual where 5% of the predicted 2.8% consumer electricity savings from smart metering are assumed to happen as a result of other policy initiatives (e.g. CERT and other delivery of clip-on real time display units). The NPV costs and benefits are £9.12bn and £14.15bn in Option 1 and £10.05bn and 15.04bn in Option 2. As the NPV of the two options are very close, Option 2 is the preferred option as it provides an earlier start, allowing for delivery of policy objectives earlier.

The benefits of smart grids were analysed by ENSG over two periods: Phase 1 from 2010 to 2020 (i.e. roll out of smart meters) and Phase 2 (2020-2050).

Figure 2.3: Smart grids benefit assessment



Source: Frontier Economics (2011), p.15 (based on ENSG 2009 analysis)

The decarbonisation of the transport sector, where all 34 million UK cars were electrified, would mean 2-2.5 times the UK power demand (UKERC, 2011). Hence, while decarbonisation of the heating and transport sectors is important for a low carbon transition, such a shift puts extra demand on the electricity system. Strbac *et al.* (2010) calculate the benefits associated with network reinforcement by demand response through smart metering. In an active network where demand response is facilitated by smart metering systems the system peaks and the need for network reinforcement can be reduced by a considerable amount. In alternative scenarios for the electrification of the heat and transport sectors, the NPV of a smarter grid is calculated to vary between £0.5bn and £10bn. The benefits from reduced generation capacity requirements, flexibility in system balancing and enhanced utilisation of the transmission network or improved outage management are not included in this study, hence indicating an underestimation of the actual benefits.

The Energy Networks Association (ENA) (2010a) calculates that additional suggested requirements (which are beyond the scope of the Supplier Requirements for Smart Metering (SRSM) project) will provide a positive net present value of c.£50m. These additional requirements cover i) measuring import/export reactive energy, ii) capability of calculating and reporting power factors, iii) storing voltage profile data for 3 months, and iv) storing loss of supply information for a specified period.

2.2 Demand-side aspects

Demand-side measures are of at least equal importance for achieving energy and climate targets as supply side measures – the traditional focus of UK policy; some argue that demand-side measures are even more important in this respect (e.g. Grubler and Riahi, 2010). Public perceptions of and reactions to electricity grid developments and potential associated smart technologies and management issues will influence the implementation, acceptance and success of a future 'smart grid' (SG). As such, studying potential demand side responses and implications for lifestyles and everyday practices becomes important for the understanding of key issues, contingencies, and possibilities for SG development. It is important to note that at this stage, SGs are not yet implemented and therefore the literature pertinent to interaction with SGs is very limited. However, relevant research exists for energy use, perception and management, as well as interactions with and potential for adoption of renewable energy, and/or micro-generation (for a recent review see Whitmarsh *et al.*, 2011), all of which are directly or indirectly linked to operational SGs.

Energy consumption and management

Energy use is susceptible to a multitude of factors: economic (income, cost, etc.), structural (location, home ownership, household size, etc.), and social (status, meaning, identity, etc.); as well as everyday (consumption) practices and habit; and –to a lesser extent– environmental values (e.g., Whitmarsh, 2009; Nye *et al.*, 2010).

When it comes to energy issues, most people tend to consider cost first (Eurobarometer, 2006) and try to understand their energy consumption from their energy bills (Kempton and Layne, 1994). However it may be difficult for the average consumer to correlate their everyday activities with their overall energy consumption (Burgess & Nye, 2008). Paying for energy has been compared to paying for groceries bought in a shop where no prices are listed, billed by a monthly statement (Kempton and Layne, 1994) and indeed nearly a third of individuals find their energy bills not very or not at all easy to understand (EST, 2008).

More importantly, concrete research findings show that energy use often moves relatively easily from initially considered deliberations over perceived personal costs and benefits, to habitual behaviour (e.g., Gardner and Stern 2002; Poortinga and Pidgeon, 2003). Despite lending itself to the use of financial heuristics or frames, most of everyday energy use behaviour is not financially driven. For example, survey work has found that 'habit' is the most common reason given for not switching off lights and appliances (Emmert *et al.*, 2010).

Stated energy conservation behaviour (i.e. measured behavioural intentions rather than actual behaviour), appear to be increasing. EST (2010b) survey data indicates the proportion of the UK public stating they are doing 'lots of things' or 'quite a number of things' to reduce their energy use and emissions increased from 19% to 38% between 2008 and 2009. However 32% report they are doing small things, and one in ten report they are unwilling or unable to reduce their energy use.

Importantly, individuals demonstrate systematic misconceptions about energy use, often underestimating the energy used for heating and overestimating the energy used for lighting as well as for appliances and cooking (Mettler-Meibom and Wichmann, 1982; Costanzo, 1986). Misconceptions also appear to correspond to popularity of energy saving actions, with actions to save electricity for lighting being more popular than heat- and washing- related energy saving actions (Whitmarsh *et al.*, 2011). Interestingly, energy *conservation* behaviour tends to be seen as quite different from energy *efficiency* behaviour (Gardner and Stern, 2002). Here, technological measures (most associated with efficiency) are viewed as more acceptable to the public than conservation behaviour (Poortinga and Pidgeon, 2003). Here again, misconceptions regard the effectiveness of conservation measures being overestimated, whilst the impact of technological measures is underestimated (Kempton and Montgomery, 1982). Notably, whilst people appear to be aware of climate change and greenhouse gas emissions associated with energy, many do not act on this awareness, particularly those in the most well-off, and environmentally-aware sections of society (e.g., Barr *et al.*, 2010; (Bibbings, 2004).

Demand-relevant measures can be classed into energy *efficiency* and energy *curtailment* measures, with different conservation potential, as well as psychological properties: people perceive energy efficiency and energy curtailment/conservation as different behaviours (Gardner and Stern, 2002; Poortinga and Pidgeon, 2003). In addition, behaviour change is generally less acceptable by the public than technological solutions – which implies that behaviours are not affected (Poortinga and Pidgeon, 2003).

In particular, **efficiency** measures and behaviours (increasing the benefit from used energy), such as purchasing high energy efficiency appliances or home insulating, are one-off or rare purchasing behaviours, and therefore susceptible to influence/change within a limited time window. They are also considered more effective than curtailment measures (Gardner and Stern, 2008). However their public acceptability is driven by costs: whereas over 75% of participants wanted to apply such measures (88% for energy efficient appliances, Warwickshire Observatory, 2008), only 44% would pay significantly more for energy efficient products (Spence *et al.*, 2010); and Emmert *et al.* (2010) specifically recognised high costs as the main barrier for adopting such appliances.

However, energy efficient appliances can greatly lower energy consumption over time, especially these continuously using electricity such as fridges and freezers, and they are only bought rarely (EST, 2009) hence influencing consumer choice in this area becomes crucial. An interesting finding in this respect is that that substantially more consumers bought appliances with energy efficiency logos in recent years (EST, 2007) and that 60% of participants who had bought an energy efficient appliance were willing to do so again in the future. It is also noteworthy that when installing energy-efficiency measures consumers choose a mixture of higher living standards and energy conservation (cf. rebound effects, Boardman, 2004).

On the other hand **curtailment** measures and behaviours (consciously reducing net energy consumption by changing energy behaviour), such as switching off the light or wearing more clothes indoors, are largely repetitive, habitual behaviours. They affect day-to-day behaviour and need to be maintained in the longer term in order to yield significant benefits.

A significant predictor of regular curtailment behaviours (but not of not of energy-efficiency) is pro-environmental self-identity (Whitmarsh and O'Neil, 2010). Within the UK, a clear majority (70%) consider reducing household energy use as a virtuous thing to do for the environment (EST, 2007), although policy measures aimed at reducing household energy use are generally unpopular: few think that measures, such as 'green' taxes (34%), road pricing (30%), and carbon rationing (28%) are acceptable, and there is no enthusiasm among individuals for changing their lifestyles.

There are also clear cultural and social associations with energy use for lighting and heating; for example, for some families it is important to maintain a warm and well-lit home so as to project an image of cosiness, even for "fuel poor" people (Shove, 2003; Harrington *et al.*, 2005). Such inconspicuous and "irrational" drivers and meanings of energy use make it difficult for social actors to reflexively change energy systems or practices (Nye, 1998; Nye *et al.*, 2010).

Attitudes are broadly positive towards energy curtailment but given the important social and cultural meaning of 'home' (safe, comfortable, self-expressive, etc.), domestic energy saving is sometimes seen as threatening (Linguistic Landscapes, 2009). Some begrudge being admonished for using energy for entertainment or comfort purposes or find energy saving devices, such as smart meters, to be intrusive in this private domain (Defra and Brook Lyndhurst Ltd, 2007; Emmert *et al.*, 2010).

We must emphasise that energy efficiency and curtailment/conservation are not mutually exclusive options. On the contrary, successful combinations of the two would maximise reduction in energy demand and facilitate energy technology adoption and behaviour and cultural change (Nye *et al.*, 2010). For example, *shifting* energy demand off-peak, while maximising efficiency and conservation at home – although progress in this area is likely to depend on future transitions in the electricity economy (see next section).

Public engagement with technologies/products relevant to SGs

Public familiarity with and adoption of relevant technologies is important for the implementation of SGs. These cover several options (and could include energy efficient devices covered in the previous section); however here we focus on novel technologies that are directly linked to a low-carbon economy and the electricity network.

Smart meters: These are real-time or near real-time devices that provide information on and potentially control our energy use (Darby, 2010). Smart meter rollouts are underway in many places around the world, with varied responses. Many countries have had highly positive responses to smart meters (e.g. Canada), while in other cases there have been delays, public opposition and even a withdrawal of policy support (e.g. California, The Netherlands). Concerns raised include inaccuracies of metering, unfair distribution of costs, benefits and risks between consumers and suppliers, health and safety (e.g. headaches, cancer, electric shocks), and privacy (see Mah *et al.*, 2011, for a review).

Assessments of smart meters show they can help to raise energy visibility and awareness (Derby, 2006; Burgess and Nye, 2008) and increase perceived control over energy use (DECC, 2011h). A saving of between five and 15% of energy savings was made possible by engaging with these devices in the US, (Darby, 2006; cf. Faruqui *et al.*, 2010) and electronic feedback has been found to be more effective than other information provision alternatives (Van Houwelingen and Van Raaij, 1989). However, growing evidence suggests the effectiveness of this approach as a *standalone* demand management tool wears off within a year or less (Burgess *et al.*, 2011). Nevertheless, public support for smart meters appears to be overwhelming (e.g., Defra and Brook Lyndhurst Ltd, 2007): in Wales, 96% of people would use a smart meter to help reduce their heating bills (EST Wales, 2009). Users seem to prefer informational feedback in monetary terms, perhaps unsurprisingly given that this is more familiar and meaningful than carbon or energy units (e.g., Kw/h) saved. However, many have highlighted that cost savings are so low that consumers may not consider it is worth the effort to reduce consumption, possibly resulting in rebound effects where people stop making an effort to save energy (DECC, 2011f). Indeed recent research shows that people who engaged in an energy saving task which focused on cost (compared with those who focused on carbon or energy units) were significantly more likely to subsequently state that saving energy was not worthwhile (Spence *et al.*, 2011).

Research has also demonstrated that simple smart meter designs are preferred (EST, 2009) although there are trade-offs between aesthetics and being informative, emphasising the ability to group information and to ‘drill down’ (Wood and Newborough, 2007). Indeed, several studies have highlighted preferences for, and benefits of, disaggregated information at the appliance level, enabling users to explore and identify the impacts of changing their behaviour (Karjalainen, 2011; Fischer, 2008).

Trials have also found that advice and demonstration when the device is installed is important; after this, the vast majority find them easy to use (EST, 2009). However, information provision alone may be counter-productive (Hargreaves, 2010) if it results in individuals feeling guilty about consumption which they feel unable to reduce, disempowered, disinterested or cynical about government attempts to ‘educate’ the public by placing responsibility for climate action on individuals. Therefore, information provision must be coupled with behaviour strategies and concrete opportunities for change. Evidence for improving performance by goal setting is strong, with specific and difficult goals being most useful, rather than just asking people to do their best (Harkins and Lowe, 2000). For example, devices could provide a visual goal to serve as a prompt to the user, potentially with the facility to be adjusted and reset by the user (Wood and Newborough, 2007). Overall, smart meters would have greater potential as part of a global attempt to maximise efficiency, conservation and load shifting, and offer a vehicle for potential influence via normative information, as outlined in section 2.2.4.

Smart Homes. This concept incorporates energy efficient, controllable domestic appliances and real-time access to energy usage data, facilitated by a network of sensors and computers. One study on public attitudes to smart homes and smart technologies found 45% of respondents were interested in living in a smart home; this proportion was higher amongst those with higher incomes, aged 15-34, in a family household, or who already owned new technology. Age correlated negatively with acceptance of smart home technology, and specific concerns regarding smart homes included the overreliance on technology, with threat of system failure (Pragnell *et al.*, 2000). Similar lack of trust in technology was observed in a Swedish trial of smart home technologies (Sandstrom & Keijer, 2010). Distrust in any benefit related to these technologies arose through malfunctions with the energy-use display early on in that study. Later resolution of these problems did not alleviate distrust. Other research finds consumer concerns about data privacy with smart technologies, particularly due to the extent of behavioural monitoring and the longevity of data storage (Lineweber, 2011; cf. Langheinrich, 2011). Here, it is important to be mindful that the performance and impact of early energy developments have the potential to substantially shape public attitudes to the sector (McLachlan, 2010). Cost of the technology also stands out as a key issue in acceptance. Smart energy saving technologies are viewed as expensive and the period over which these may justify their purchase is important in determining acceptance (Roberts *et al.*, 2004).

Notably, interaction with smart technologies can be active, where the consumer responds to information or price signals in order to change their energy behaviour, or passive, where the supplier or network takes control of the technology in order to increase efficiency. There is currently little in depth information consumer preference for active or passive smart technology control. With active demand responses, there is no guaranteed change in demand, responses are likely to be less efficient (Defra, 2008b) and there may be potential for information overload on the consumer resulting in signals being ignored. While it is likely that some people may not accept externally controlled domestic appliances, survey data indicates that most respondents are willing to allow *some* control of domestic devices and many were willing to consider postponing the start of a washing machine, tumble dryer or dishwasher cycle (SMART-A, 2008). Moreover, users tend to prefer automatic control where operation responds to critical pricing incentives, thereby reducing costs (IEA DSM, 2007).

Renewable/differential energy tariffs. Uptake of renewable energy tariffs by households has been extremely low (0.3%). Awareness of green energy schemes is also relatively low: 63% of an English sample did not recognise any green energy suppliers/schemes' names or logos, and 83% had never used them (Haddock Research and Branding, 2008). Reasons for low take-up include the cost of tariffs, limited information on green energy, the effort involved in switching supplier (switching 'inertia') and low levels of public trust about the environmental benefits of green energy schemes. Differential energy tariffs, which can help spread demand, are viewed positively by many (but not by all) because of their association with cost reductions, though most UK respondents were unfamiliar with the concept and several thought that it was not practical to shift practices such as washing the clothes during the day or night; and there was a significant level of distrust towards energy companies in terms of raising prices once consumers switch to off-peak tariffs (Defra and Brook Lyndhurst Ltd, 2007).

Microgeneration. Local energy production – especially from renewable sources – becomes very important for a low-carbon electricity economy, and essential for a decentralised version of the energy system. Decentralised energy systems have important social, psychological, technical, and economic benefits, not least of which the establishment of energy citizens and subsequent emergence of new roles and dynamics in the community (Devine-Wright, 2007). For some, generating their own electricity and self-sufficiency is a source of pride. Indeed, if 'eco' can be reframed from a rational argument to a positive emotional discourse, it may help the uptake of greener domestic technologies/practices (Linguistic Landscapes, 2009).

People who chose to install micro-generation or live in a house where it has been installed feel proud, independent, and enjoy talking to others about the technology. The installation of micro-renewables may also be a catalyst for householders to engage emotionally with the issue of energy use. Installing micro-generation, or living in a house with existing installation, makes people more aware of their energy use and the need to save energy in other ways (Hub Research Consultants, 2005). By becoming responsible for generating their own energy, householders also assume responsibility for consuming it. Passive households in particular demonstrate the potential impact of micro-generation: whereas, during a study, active householders tended to be conscious environmentalists whose chose to install micro-generation to make a stand, passive households generally had much less energy awareness before installation. However, living with the technology encouraged greater understanding and awareness around energy issues and often impacted on energy-related behaviours (Hub Research Consultants, 2005). Nevertheless, the high upfront capital cost is a major barrier to uptake of micro-generation (e.g., London Renewables, 2003). Additional barriers include lack of awareness or understanding of the options (particularly for heat pumps); long payback times; uncertainty as to efficiency, effectiveness, consistency and environmental performance; difficulty in finding credible installers and suppliers; concerns about ease and costs of maintenance; and the inability of renewable technologies to satisfy all heat requirements (e.g., Ellison, 2004; Caird *et al.* 2008). Trials of heat pumps suggest performance depends on householder behaviour, and many participants reported difficulties in understanding operating instructions; nevertheless, well-installed heat pumps led to carbon/energy savings for customers off the gas grid (EST, 2010a). Qualitative work with landlords suggests that, for this group, financial criteria are even more important than for other demographics when considering micro-generation (Carney and Upham, 2011). At least some of the above barriers can be overcome with the provision of adequate subsidies.

Electric vehicles. These are briefly mentioned here, due to their potential to contribute electricity storage to SGs, aiding peak smoothing and promoting the use of differential tariffs. Currently, less than .5% of vehicles on the road are electric or hybrid (Defra, 2009). One in four UK drivers would consider an electric car next time they buy a new car (EST, 2010c) but almost half of the respondents did not know if they could use an electric car where they live. Although more agreed that the image of electric cars had improved, few thought they would perform as well as a conventional car for many types of travel (EST, 2010c). Most people agree the government should do more to persuade people to buy fuel-efficient cars (including electric cars; DfT, 2010) and that environmentally-friendly car drivers should pay less tax (Park *et al.*, 2008). These trends show that despite their early stage of implementation, electric vehicles can be important for SG deployment. Their rate of adoption will help shape SG deployment, and pricing/subsidies appear to be an essential for this process.

In general, then, the public seems to support changes in energy supply and consumption, if their quality of life remains the same and if government and business lead the way in creating conditions that will allow users to make the necessary changes. Such conditions include well-designed, low-cost, energy-saving and micro-generation technology packages, with public estates (e.g. schools, NHS buildings) leading by example (Whitmarsh *et al.*, 2011).

Centralisation, distribution and cooperation

Combining most of the above solutions and approaches, Nye *et al.* (2010) summarise the central role of domestic customers in two possible transitions to low-carbon electricity systems. In a *centralised* system transition, price incentives or real time displays can only offer limited energy savings as customers may not always respond "as expected" to price signals and 80% of energy consumption is considered non-discretionary. However, the combination of price incentives and real time displays/smart meters offers augmented potential for energy load balancing via energy use behaviour change. This could in turn increase potential for the use of renewable sources of energy (e.g. off peak tariffs offered during optimal output from renewables) offering the opportunity for consumers to actively influence their energy mix, and for suppliers to reduce costs and improve carbon emission targets. Perhaps more importantly, there is significant potential for habit disruption and therefore achievement of real behaviour change in this scenario. Issues remain, however, with regards to whether customers will indeed respond as expected to these options, how the transition from traditional energy suppliers to Energy Service Companies may be achieved, and what incentives can convince large suppliers to change their business models. In a *decentralised* system transition on the other hand, the energy citizen – consumer – co-producer asserts a central role in the production and demand equilibrium, with the potential for dramatic reduction in domestic electricity demand. As users will produce significant portions of their required electricity and enjoy partial independence from the grid, they will also tend to significantly shift their electricity consumption in line with their production, disrupting energy routines and alleviating the grid from peak pressures and relevant costs.

Nevertheless, there are significant barriers to overcome in this scenario including very high installation costs, planning, installation and public scepticism on whether such change can be effected. In addition, current energy production and distribution players will resist change. These barriers point to the crucial role of subsidies, regulation and government leadership in reshaping the landscape and helping consumers and the industry through this transition.

Acceptance and cooperation between participants in distributed energy networks (where there is more than one stakeholder) is essential for successful operations and considering current evidence on these issues is important. The potential for virtual energy networks in helping to coordinate distributed energy resources is another important aspect of future smart grid scenarios, e.g. microgrids, virtual power plants (Pudjianto *et al.*, 2008), but ultimately relies on the acceptance and cooperation of those who own those energy resources (Wolsink, 2012). On a smaller scale, many of the same issues are relevant within shared buildings (e.g. multi-tenanted buildings). There is currently little applied evidence regarding cooperation around energy resources; however research within psychological literature on cooperation and the broader environmental literature also speaks to these issues.

One such example is the positive influence of social or group norms on behaviour: people are more likely to undertake sustainable behaviour when encouraged by peers and when this behaviour is visible to peers (Cialdini, 2003). Whilst direct comparisons between households seem unpopular and participants are sceptical over the accuracy of comparisons (Roberts *et al.*, 2004; Wood & Newborough, 2005), other types of interactions between people around energy conservation, sharing and cooperation may be beneficial. For example, if an individual can see others reducing their energy use, they are more likely to do the same (Schultz *et al.*, 2007).

Energy meters illustrating energy conservation by others may therefore encourage others to do the same. Importantly, it is also shown that when others are not reducing energy, this information can act as a disincentive to conserve energy, but this can be countered by conveying social approval for conservation actions (e.g. simple happy face icons). Similarly, acceptance of distributed energy resources (e.g. wind turbines, wood pellet boilers), is positively influenced by the support of significant others such as friends and family and negatively influenced by the reaction of neighbours and other local residents (Claudy, *et al.*, 2011).

Energy network contexts and cooperation situations may complicate these kinds of social influences due to the repeated nature of interactions and the potential for agreeing goals alongside basic monitoring and available information. Indeed, lack of cooperation is often felt as a barrier to conserving energy (EPRI, 2011) and individuals are likely to become discouraged in their sustainability efforts if they feel like they are the only one contributing (cf. the ‘Drop in the ocean’ feeling; Lorenzoni *et al.*, 2007). Moreover, early research on public perceptions of cooperation around smart energy technologies shows that the idea of working together as a group was found to be quite overwhelming and complex, potentially frustrating participants if not everybody involved would cooperate (EPRI, 2011).

As noted by (Wolsink, 2012), distributed energy networks may be considered as common property (owned and managed by members of the network) that generate a common good. This depends on how the network is owned, managed and controlled. Importantly, there may be divergent incentives where private and social benefits differ for individuals who contribute less, or who take more from the common good than others (c.f. “free riding”). Cooperation tends to decrease as group size increases (Hamburger, *et al.*, 1975) and anonymity and visibility of actions decrease. However, larger group sizes are not always observed to decrease cooperation as in large groups the presence of a small number of people who do not cooperate is bearable and here participants are often better able to form cooperative clusters where non co-operators are avoided (Szolnoki and Perc, 2011).

Perhaps unsurprisingly, people tend to behave more cooperatively with those they are familiar with and more similar to (Alexander and Christia, 2011). Energy networks may therefore be more successful in already established communities, and within specific geographic locations, rather than in terms of virtual networks linked only in terms of resources. Indeed, research on the acceptance of micro-generation shows that schemes which involve the community and build on current community identity are generally the most successful. Further, institutions that integrate communities can increase cooperation, particularly where regulation and sanctions are available to ensure and reassure participants of mutually beneficial behaviour (Alexander and Christia, 2011). Indeed social capital and the ability to monitor and enforce resources and resource use are highlighted as key features of effective common resource governance by Dietz *et al.* (2003), as well as the ability to exclude outsiders at a relatively low cost and allowing only moderate rate of change in the network and resource management, features which would defend against sudden shocks to the resource pool and protect trust within the network.

We acknowledge that there is a dearth of applied evidence here and early examples of energy network test beds will be invaluable in discovering characteristics of successful network systems.

Public understanding of energy systems and smart grids

So far, we have discussed literature relevant to behavioural aspects of SGs – that is, how the public might be expected to act when SGs are deployed. This is largely inferred from related technologies, such as smart meters. We now turn to research which has explicitly asked the public about how they understand energy systems in general, and smart grids in particular.

Devine-Wright and Devine-Wright (2009) explored public beliefs about electricity supply. Understanding of the grid is variable: some made links to familiar technology networks (e.g. broadband internet), while others had sophisticated understandings of UK/international networks (Devine-Wright and Devine-Wright, 2009). Respondents were ambivalent towards large-scale network infrastructure: pylons were perceived to be impressive engineering feats and iconic of the network, yet imposing, unaesthetic, and linked to health risks (e.g., leukaemia). This was replicated in a follow-up study, which also found high support for underground power lines (Devine-Wright *et al.*, 2010). The meaning of 'national' was also debated, with Scottish participants blaming demand for electricity in 'the South' (i.e. in the South-East of England/London) for imposing electricity infrastructure upon Scottish rural communities, without local benefit.

Participants' understanding about how electricity reaches the home focuses primarily on technologies (e.g., cables, wires) and familiar devices (e.g. TVs) rather than distant components of the network (e.g. sub-stations, pylons); in addition, organisations operating the network (e.g. National Grid) are unfamiliar and not trusted (Devine-Wright *et al.*, 2010). This research also highlights community suspicion of energy companies and low expectations of public involvement in power line planning decisions (Devine-Wright *et al.*, 2010). This lack of a systemic concept of the grid, and the relative invisibility and mistrust of organisations is problematic for public responses to smart grid proposals (Devine-Wright and Devine-Wright, 2009) if such proposals include visible components. However, this is not necessarily the case, and the definition of SGs is still fluid, with a general consensus that any changes on the grid itself (i.e. excluding new generation) will be invisible to the public. For example, in one of the very first attempts to define a social construct of SGs, Wolsink (2012) found only minimal physical elements, with the majority of perceptions focusing on the possible *functional and social aspects* of a SG. This is in favour of SG developments, as public sentiment will not necessarily be affected in terms of visible developments (e.g. as opposed to installing new wind farms).

In addition, recent research suggests public concern about energy security, including reliance on foreign imports, is high (Spence *et al.*, 2010). For example, 70% of the public is concerned about the increasing imports of gas from abroad (Ipsos MORI, 2010). This concern increases with age, being greater than average among the over 45s, and among the ABC1C2 social groups, and provides fertile ground for framing smart grids development around energy security, in order to increase their acceptability at least for some social groups. This is reinforced by research showing that blackouts are considered unacceptable and ‘out of place’ in a developed country such as the UK. Interestingly, short-term outages were also felt by some to provide opportunities to escape from restrictive social norms and community interaction (Devine-Wright and Devine-Wright, 2007).

Public awareness of smart grids is extremely limited. Deliberative research to elicit public responses to the concept suggests some groups express interest in the technology, if it afforded financial benefits (EPRI, 2011) although concerns about data security were also raised. Other research finds public support for SG technology, but a lack of trust in utility companies to pass on the associated benefits to consumers (Lineweber, 2011). Specifically the issue of trust towards the developer of SG technologies seems to be fundamental for their success, and therefore meaningful public engagement is necessary from the inception of any relevant project (e.g. Alvial-Palavicino, *et al.*, 2011).

Public perceptions of energy systems and scenarios. There is little work on public attitudes to energy systems and scenarios. The Big Energy Shift for DECC/OST (Ipsos MORI 2009) found people are supportive of changes in energy supply and consumption, providing their quality of life remains the same and that they are helped to change (see also Carney and Upham, 2011). There is dearth of data in this area at the time of writing, and current UKERC and DECC projects are also exploring public opinion of energy scenarios (including using the DECC My2050 tool).

2.3 Policy and Regulatory Aspects of Smart Grids

This section will consider the current regulatory framework of the UK electricity supply industry (ESI) as it relates to smart grid development, setting out the policy drivers which underlie the need for smart grid development and the limited smart grid related initiatives already underway. It will discuss some of the underlying issues relating to the current regulation of the ESI and the potential for conflict between these and the way that grid investment and market operation will need to operate as anticipated policy driven generation and consumption changes take hold. It will outline the current state of policy specific to smart grids and smart metering. It will discuss the barriers to the changes that the UK wishes to bring to the ESI and to the adoption of smart grids as a partial solution to some of the challenges thrown up by the necessary evolution of the UK ESI. It will discuss the changes that will need to be introduced and which are already being introduced to enable the solutions that are increasingly likely to be required for smart grid deployment.

The UK has already taken action to adopt policies specific to implementing the shift in energy production to renewable energy sources. Additionally it is considering the infrastructural requirements of making these changes. This section will consider the key drivers for smart grid development in the UK, as a solution to future energy system challenges and as a method for reducing the costs of meeting these challenges.

Policy Drivers for Smart Grids

The UK has legislated a policy goal of an 80% reduction in national climate change emissions by 2050; further to this the UK has a legal obligation under EU law for 15% of all energy consumption to come from renewable energy sources by 2020 (Great Britain Climate Change Act, 2008; European Commission, 2009b). This change will need to occur in the context of an energy system which will see up to a quarter of existing electricity generating capacity close down as nuclear and coal power stations reach the end of the operational life. The UK is thus faced with the task of developing policy which will address challenging environmental and security of supply issues, whilst controlling the economic costs of their response such that access to energy for both domestic and commercial consumers is manageable. This will require changes in how energy markets operate, how networks are regulated and incentivised, how consumer demand is managed (and how consumers manage their own demand) and in how investment in meeting these challenges can be incentivised.

There is no doubt that substantial direct investment as well as investment in infrastructure will be required. The UK's Department of Energy and Climate Change (DECC) and Ofgem estimate the total investment required could total as much as £200bn by 2020. This represents approximately a doubling of the historical rate of investment (Ofgem 2010b).

In order to achieve the UK's renewable energy commitment, the UK government has set an ambitious target specific to renewable energy sources of electricity (RES-E). DECC's Renewable Energy Roadmap states that around 30% of electricity should come from renewable energy sources if there is to be any chance of achieving the renewable energy target. This represents a significant increase from the 6.8% of electricity that was sourced from RES-E in 2010 (DECC 2011a). DECC's expectation is that the majority of this additional RES-E capacity will come from onshore and offshore wind (DECC, 2009b; DECC, 2013).

While the latter is predictable, wind is more intermittent in nature and there are concerns as to the flexibility of current trading arrangements in dealing with this volume of intermittent generation capacity or of providing sufficient incentives to keep alternative capacity available in order to maintain security and reliability of supply.

Further, the addition of large volumes of new capacity is likely to be in locations which do not currently have sufficient grid capacity to deal with its connection, and this is in addition to the need for expenditure of ageing elements of the UK ESI. There is concern that the current system of price signals may not allow sufficient incentives for sufficient investment in either the transmission or distribution network operators. Ofgem's Project Discovery outlines five key areas which represent key challenges for UK energy supply:

- There is a need for unprecedented levels of investment to be sustained over many years in difficult financial conditions and against a background of increased risk and uncertainty. The project suggested that the requirement for investment might be as high as £200bn up to 2020 if environmental and other goals were to be met, suggesting a rate of investment twice as great as the typical rate to 2010. A figure of £32bn has been estimated for the required enhancements of the electricity and gas networks, a figure which represents around 75% of the total value of the networks currently (Ofgem 2010b; Ofgem 2010c).

- The uncertainty in future carbon prices is likely to delay or deter investment in low carbon technology and lead to greater decarbonisation costs in the future.
- Short-term price signals at times of system stress do not fully reflect the value customers place on supply security which may imply a requirement for stronger incentives to make additional peak energy supplies available and to invest in peaking capacity.
- Interdependence with international markets exposes GB to a range of additional risks that may undermine security of supply.
- The higher cost of gas and electricity may mean that increasing numbers of consumers are not able to afford adequate levels of energy to meet their requirements and that the competitiveness of industry and business is affected.

Source: (Ofgem, 2010b).

Thus the development and evolution of effective smart grids and the achievement of the goals associated with smart grids will require significant changes in multiple areas of electricity delivery and consumption. It will necessitate changes in the motivations and behaviour of multiple existing stakeholders including policy makers, regulated and competitive utilities, investors, consumers and regulators, as well as changes which will encourage new entrants to the energy sector and encourage innovation in technology, service provision, grid and other management by both established and new stakeholders. The degree of change that will be tolerated by stakeholders will shape the political acceptability of the degree to which smart grids evolve and are adopted. Policy makers may respond to the need for change to different degrees and will be influenced by the potential for cost and carbon savings, the opinion of other key stakeholders and the representation of the issues which emerge from the press in the wider context of public opinion.

The UK Government and GB energy regulator, Ofgem, have acknowledged the need for change in the policy and regulatory framework and begun the process of changing key elements of the system. These changes will reform the electricity market, change the incentives for key stakeholders and create instruments which will directly impact on the shape of smart grids, as well as the services that can be made available using smart grids and smart technologies. These changes have the potential to complement or block increasingly smart networks and drive forward the achievement of policy goals, which will make a greater case for the economic and technological benefits that smart grids might bring.

The key elements of the current governance response to the anticipated changes in electricity supply manifest through two key instruments: the Electricity Market Reform (EMR) and the regulatory shift from RPI-X to RIIO. EMR is a move rooted in primary legislation and driven by the Government while RIIO will change the regulatory incentives for network operation. Both are likely to transform the behaviours of investors and other stakeholders, allow greater flexibility in the electricity system and may make targets easier and more cost effective to achieve. They should also serve to drive innovation in environmental technologies and the smart grid technologies, which it is hoped, will enable them. Along with other policy initiatives they are intended to drive the changes needed for the UK to meet its sustainability goals, to ensure security and reliability of supply and to achieve both goals while limiting costs to both commercial and domestic consumers.

A shift to smarter grids, with smart meters and smarter approaches to supplying electricity, as well as demand side management, are seen as key methodologies in keeping down costs, while at the same time widening consumer choice and improving consumer understanding and management of their consumption.

Policy Instruments that will drive up the Value of Smart Grids

Increasing Renewable Electricity Generation

The UK currently has two key financial support instruments to support the growth of RES-E; the more significant of these will be slowly replaced within the context of the EMR. Additional mechanisms support growth in renewable energy sources of heat (RES-H).

The Renewables Obligation (RO) is currently the central mechanism for supporting the growth of large-scale RES-E in the UK. It is a quota mechanism which creates demand for RES-E amongst supply companies by compelling them to either purchase RES-E from RE generators or pay a penalty for each unit by which it falls short (Mitchell and Connor, 2004; Woodman and Mitchell, 2011).

The RO represents a substantial financial stimulus and has driven growth in RES-E from 4.5% in 2006 to 7.4% in 2010 (DECC, 2011a). The major technologies the RO has driven, to date, are onshore and offshore wind and biomass combustion for electricity generation. The UK Renewable Energy Roadmap predicts that wave, tidal, ground and air source heat pumps, as well as biomass combustion for heat are also likely to see significant expansion up to 2020 and beyond, while other technologies may also make contributions.

The greater part of the expansion of onshore wind is likely to be focussed in Scotland. Extensive rounds of offshore wind expansion are likely to be centred on sites in the Moray Firth, Firth of Forth, North Sea, the Irish Sea and then in limited locations in the English Channel and Bristol Channel. This will require considerable investment in transmission and distribution network expansion, as well as presenting challenges in terms of the management of large volumes of intermittent generation (DECC, 2011g).

While the RO has driven some growth in RES-E, it has been compared negatively with tariffs applied in many other EU Member States and will be phased out between 2013 and 2017 in favour of Contracts for Difference (see below), a tariff like financial instrument that is being introduced as part of the Electricity Market Reform (DECC, 2011d).

Another method of stimulating the renewable electricity market is the Feed-in Tariffs (FiTs) Scheme. Introduced in April 2010, FiTs provide a fixed payment for generation from RES-E plant under 5MW of capacity. The scope is much less ambitious than that of the RO but holds the potential for turning millions of small consumers into consumer-generators. This will add levels of complexity to managing distribution networks and may require some of the technical solutions that will follow into the classification of smart grids. FiTs have been subject to a number of modifications since their introduction and came under review in 2012 following concerns about the level of payments in comparison to rapidly falling prices in specific small-scale RES-E technologies (DECC, 2011b).

While the scale of the capacity supported will be considerably less than in the RO or its replacement, microgeneration has the potential to aid the UK in meeting its renewable energy targets and technologies such as domestic solar PV have proven to be generally popular with consumers. Since this scale of technology will tend to connect directly to the distribution grid, a large-scale roll-out offers technical challenges in terms of managing intermittent generation and demand on distribution networks.

Renewable Heat Incentive

The UK is in the process of introducing what can be regarded as a pioneering policy instrument to provide financial support to renewable energy sources of heat. The Renewable Heat Incentive (RHI) will provide a fixed tariff per unit of heat energy produced from eligible technologies (DECC, 2011f). The key technologies likely to be stimulated are biomass boilers, ground source heat pumps and solar thermal. The UK Renewable Energy Roadmap identifies air source heat pumps as having the potential to contribute significantly to UK RES-H generation, producing up to 9 TWh/year by 2020 (against 14 TWh/year from ground source heat pumps) but the technology is not included in the RHI as yet, and while this remains the case it is unlikely to be economically viable to the extent that it is significant (DECC, 2011g).

The RHI is significant in terms of future UK electricity demand for a number of reasons. The most important is that several scenarios for uptake of RES-H technology suggest the possibility of large-scale uptake of heat pumps, pushing up electricity demand relating to heat in commercial and domestic properties. The RHI will be at the forefront of the initial expansion of heat pumps. The expansion in the adoption of heat pumps also presents some danger of an increase in electricity use for cooling in the domestic sector, if installation of reverse cycle heat pump systems leads to comfort taking by consumers who would not previously have had access to cooling (Speirs *et al.*, 2010).

The RHI will also change the economics of biomass CHP systems, potentially increasing the volume of new capacity in this area, and adding to the number of small distributed electricity generators active in the UK.

Zero Carbon Homes and Non-Domestic Buildings

The UK has adopted policy to reduce the emissions related to climate change that are associated with energy use in new homes and other buildings (Defra, 2008a; Al-Hassan, 2009; CLG, 2010). While the proposals were diluted to some extent by the new UK Government in 2011 (HM Treasury, 2011) they have the potential to drive up the use of renewable energy systems since matching installed renewable energy against energy demand in the building earns credits to raise the rating of the building.

Electrification of Transport and Heat

The UK Government's short-term plans for reducing emissions from transport are focussed on legislating that a minimum fraction of road vehicle fuel comes from biofuels; this is unlikely to impact on the ESI. However, a number of scenarios for long-term reduction of emissions from transport fuel are rooted in the electrification of transport (DECC, 2009b; CCC, 2010).

There are two current policy instruments in place to support electrification of transport in the UK. 'Plugged in Places' is a Department for Transport project funding early stage infrastructure in eight urban centres. Electric car purchasers can also receive a grant of 25% (to a maximum of £5,000), with 982 grants approved by the end of 2011 (DfT, 2011).

Many of the scenarios which predict this electrification of transport also predict a shift to greater use of electrical energy for heating purposes, albeit through the use of heat pumps rather than direct application in space and water heating. These predicted shifts would impact significantly on both overall demand and on peak demand, and would impact on the resilience of local grid networks; significantly increasing the complexity of their management. The expected shift could double peak demand and substantially drive up total electricity demand. Smarter grid and network management, combined with enhanced capacity for demand response could offer substantial value in addressing the demands that this would place on the network, without requiring a doubling in available capacity to meet the peak demand (DECC, 2009b; CCC, 2010; Speirs *et al.*, 2010).

Electricity Market Reform

The Electricity Market Reform (EMR) is the Government's policy and legislative initiative aimed at putting in place instruments which will support the UK in meeting its low carbon energy goals while maintaining capacity margins. The EMR will provide incentives for RES-E technologies, which generate intermittently, and could potentially result in significant growth in the large-scale use of heat pumps or electric vehicles.

The Government ran consultations through 2012 and initiated the legislative process in the latter part of that year with an aim of providing support from spring 2014. The core initiatives presented in the EMR are described below.

Contracts for Difference

The Feed in Tariff with Contracts for Difference (FiT-CfD or just CfD) were announced as part of the EMR in July 2011 (DECC, 2011d). CfD will replace the RO as the mechanism for providing finance to support the development of large-scale RES-E in the UK and represent a significant change in the approach to funding in this area. However, the key RES-E technologies supported under CfD are likely to remain the same as under the RO, and largely present the same challenges. The CfD will be introduced from Spring 2014 and the RO will cease to accept RES-E generators for accreditation from March 31st 2017. All RES-E generators will have a one-off option to elect to stay with the RO or move to the CfD before 2017 (DECC, 2011d).

The CfD mechanism is somewhat different from the typical FiTs employed in many EU Member States. The CfD system will see a contract between a RES-E generator and a contracting counterparty. RES-E trading centres on a 'strike price', a pre-agreed unit price. When the market price for the electricity (the reference price) is below the strike price the generator is paid the difference between the market price and the strike price. However, when the reference price is above the strike price, the generator pays back the difference. The goal of this is to ensure a stable price for the generator. This adoption of a more stable price regime can be seen as a response to the criticism of the RO and the lack of certainty it engendered, but it is not yet clear whether the CfD will offer any substantial advantage over the FiTs mechanism employed to support RES-E elsewhere in the EU and which is regarded as being largely successful in doing so (Haas and Panzer *et al.*, 2011; Haas and Resch *et al.*, 2011).

Carbon Price Floor

The Electricity Market Reform as currently proposed, includes the adoption of a carbon price floor (CPF) (HM Treasury and HMRC, 2010). This is a response to the problems that have undermined carbon pricing since the introduction of the EU Emissions Trading System, wherein price volatility has undermined the value of carbon and increased the uncertainty associated with investment in low carbon technology. The measure came into effect in April 2013; the expected impact of this will be to provide additional financial benefits to renewable energy and other low carbon technologies relative to other energy technologies, with a resulting increase in their uptake. The CPF was announced in the 2011 Budget and the intention is that it will start at around £15.70/tCO_2 on its introduction in 2013 and rise following a straight line to £30/tCO_2 by 2020, then continue rising to £70/tCO_2 in 2030 (all figures are 2009 prices) (DECC, 2011d).

Emissions Performance Standard

The 2011 EMR White Paper announced that the Government intends to apply an Emissions Performance Standard (EPS) of 450g CO_2/kWh to any new generating capacity. This would effectively mean that any future coal power station would have to integrate a working Carbon Capture and Storage (CCS) system. This represents a substantial shift in policy from a requirement for new coal power stations to be CCS ready. It is notable that the UK's programme for innovation in the field of CCS is currently struggling, with all utilities having withdrawn from projects to access the £1bn of public funding made available to support large-scale projects. Exemptions to the EPS limit apply to any new coal plant taking part in UK or EU CCS research projects.

The Government also states that the EPS is intended to send a price signal to the markets to construct new gas capacity in the short term so as to address the significant drops in available capacity as coal and nuclear plants go off line (DECC, 2011d).

Capacity Market

The EMR announced the intended introduction of a capacity mechanism based on a prior consultation process, and a consultation on the nature of this mechanism resulted in the announcement of the intention to introduce a Capacity Market (DECC, 2011e). This will be a market-wide instrument which aims to contract capacity to meet times of peak demand. The aim is to provide sufficient incentive for investors to guarantee availability of capacity. The Government has made it clear that this will include non-generational capacity such as demand side response and storage as well as generating capacity. Provision of demand side response would certainly be a market that could – at this stage in theory – be facilitated by a greater emphasis on smarter technology and management of networks.

Current UK Policy Specific to Developing Smarter Grids

Specific UK policy initiatives for the facilitation of smart grids are limited thus far, though this is not unusual in comparison with other nations. The UK is fairly advanced in plans to roll out smart meters.

Smart Meter Rollout

The adoption of a programme to rollout smart meters to replace all current electricity and gas maters is the most significant concrete policy initiative relating to the development of smarter grids in the UK. Government figures suggest the estimated cost of the programme to be £11.3 billion, while reduced consumption of energy could potentially yield savings of £18.6 billion (DECC and Ofgem, 2011b). The cost of rolling out smart meters will be borne by supply companies but they will be able to pass this on to consumers.

The rollout of smart meters is in its early stages at time of writing, with installation largely on a voluntary basis for consumers within schemes set up by utilities who wished to initiate installation early. The Government expects to see smart meters used as the standard replacement for 'dumb' meters where replacement was due anyway from the latter half of 2012, with an accelerating schedule of installation from 2014, and the replacement of meters more rapidly than would otherwise have been the case. The programme as a whole is intended for completion by 2019.

Installation of smart meters in larger non-domestic sites is intended to be complete by 2014, though it is not clear how consumers will react to widespread installation and a negative response may yield practical difficulties (DECC and Ofgem, 2011b; DECC and Ofgem, 2011a; Committee of Public Accounts, 2012).

The data collected by the supply companies is likely to have significant value to them, their competitors and potentially also to network operators. The issue of data protection and privacy is raised in the Government proposals, which note the potential to reveal data about the lifestyle of individual consumers. The Government expresses a preference for a system it refers to as ‘privacy by design’ wherein information not specifically required to meet regulated goals (e.g. payment for supply) is private unless the consumer makes it available. It suggests regulated duties will be narrowly defined to maximise privacy. The proposal document also highlights the need for collected data to be held securely and sets out guidelines for this (DECC and Ofgem, 2011b).

Consumers will have access to at least 13 months of data concerning their consumption and should ideally be able to make their data available to supply companies and websites which compare prices and recommend switching between companies.

A number of concerns have been raised by the UK’s Public Accounts Committee (PAC) about the plans to roll out smart meters. These include:

- The costs of the switch will add to energy bills but benefits such as reduced meter reading may not be passed on.
- That consumers may not know how to reduce costs using their smart meters and suppliers have no guidance or regulatory obligation to instruct them.
- There is no defined strategy for ensuring more vulnerable consumers enjoy the benefits of smart grids.
- Consumer attitudes to widespread adoption of smart meters may affect rates of adoption. The PAC also expressed concern that DECC should have a more robust approach to scheduling and ensure adequate responsiveness to barriers to the timely roll out.
- The ICT installed to utilise the data from smart meters may not be sufficiently flexible to deal with the demands of future smart grid innovation, requiring further expenditure over and above the £3billion it is currently expected to cost.

(Committee of Public Accounts, 2012)

The UK body for protection of consumers in energy matters, Consumer Focus, highlighted the concerns of the PAC in January 2012 regarding ensuring savings rest with consumers rather than the supply companies. The current Energy Minister, Charles Hendry has responded that this will be a key concern in the smart meter implementation and subject to ongoing consultation.

This debate is notable since it emphasises the potential difficulties of the move to developing smart grids. The roll out of smart meters represents only a very early step in the move to smarter energy delivery and consumption, yet already there is conflict as to how to ensure there are benefits, to whom the benefits accrue and how to ensure costs and benefits apply equitably. Effective policies to drive smart grids, creation of appropriate policy instruments and their integration into an evolving body of regulation will be a more complex task still, and one with many potential pitfalls.

Concern has also been expressed that the supply companies might take the opportunity of replacing meters to sell their own products. The consumer rights body 'Which?' has been running a campaign "No selling, just installing" – asking utilities to commit to refrain from doing so. By January 2012 a number of minor utilities, but only one of the big six supply companies, had made the commitment (Which?, 2012a) and in April of that year the Government responded by banning the practice of using the installation of smart grids as an opportunity to sell additional products (Which?, 2012b).

The smart meter rollout as currently intended should bring the UK into compliance with the European Electricity Directive which commits EU Member States to achieving deployment of smart meters to 80% of consumers by 2020. (European Commission, 2009a).

Regulatory Issues

A large number of barriers to the shift of the UK ESI to some form of smart grid arise from the UK's regulatory framework and how it has been applied to the ESI. The light touch approach to regulation led to a disconnect between applied regulation and UK Government priorities on key issues, perhaps most notably social and environmental issues relating to energy supply (DECC, 2011c). This has meant that wider societal concerns adopted by policy makers have been slow to translate into regulations applied to the ESI.

Ofgem's duties have evolved since privatisation but this has been a slow process and has tended to require Governmental intervention on an ad hoc basis in order to change what Ofgem can legally do, either through primary legislation or through the provision of Public Service Obligations (PSOs), which typically also require legislation. The UK Government has also made efforts to align Ofgem's actions with national policy goals through the provision of guidance on environmental and social goals as an element of the Utilities Act 2000, which meant Government could give regular guidance on expectations. However, a recent Government review suggested the use of guidance was not effective in aligning Government goals with Ofgem actions for a number of reasons: weak legal status in comparison to Ofgem's other duties; weak arrangements for accountability; the Government sometimes allowing guidance to become out of date; and the scope of what Ofgem can do in response to changing policy priorities failing to include issues such as security of supply (DECC, 2011c).

The key changes which have been made to Ofgem's duties codicil their primary duties such that they must have regard for both sustainable development and security of supply, and add secondary duties for Ofgem that require the regulator to "secure a long-term energy supply" and carry out its functions "having regard to effect on the environment". DECC also emphasises the need "for an enduring solution that sees Government clearly taking responsibility for setting strategic direction, providing greater certainty for market participants, communicating strategy more effectively, and so avoiding *ad hoc* interventions where possible" (DECC, 2011c).

The Government response is to introduce a 'Strategy and Policy Statement'; the goal of which is to enable investment in the UK energy sector to be secured as cost effectively as possible. The strategy will do this by ensuring greater coherence between the policy priorities of the UK Government with the duties and thus actions of the regulator.

The Evolution of the UK Regulatory Regime and Smart Grids

The initial regulation of the privatised UK ESI was designed with the primary goal of minimising costs to the consumer, either through competition in the generation and supply functions or through regulation and incentivisation of the networks. Over time political motivations have seen greater emphasis placed on factors other than cost, these include environmental considerations (most notably climate change targets), security of supply and other social considerations such a fuel poverty.

The UK privatised its electricity supply industry (ESI) in 1989/90, opening first the generation (1990) and then supply function (1992-98) to competition, with distribution and transmission also sold into the private sector and regulated to drive down prices through benchmarking and the use of the RPI-X mechanism. The UK regulator suggests that this regulation of the latter two functions have led to a 50% in the costs of network provision in the UK in the period 1990-2010 (Ofgem, 2010c).

Successive UK Governments have supported a system of light touch regulation of energy utilities, with Government providing a list of duties through legislation and the regulator legally obliged to operate within these parameters, but with flexibility within them. The Office of Gas and Electricity Markets (Ofgem) has been the regulator since 2000 when the previously separate electricity and gas regulators were conjoined. Ofgem is governed by the Gas and Electricity Markets Authority (GEMA), which is responsible for strategy, setting of overarching policy priorities and acting as the final decision maker on price controls and enforcement of regulation. The powers of the regulator as regards the UK ESI stem from statute, most notably the Electricity Act 1989, the Utilities Act 2000, the Competition Act 1998, the Enterprise Act 2002 and the Energy Acts of 2004, 2008 and 2010.

The central goal of the regulator as regards the UK ESI is to minimise costs to consumers, a duty which manifests primarily through promoting appropriate competition and via the regulation of the grid monopoly industries. Ofgem has responded to some degree to government policy goals and has increasingly adopted an approach which broadens its approach to social and environmental goals, where this can be justified within the scope of its duties.

Innovation in the UK ESI

The development of smart grids, whatever shape they may eventually take, is rooted in innovation. Innovation in policy and regulatory ideas will be required to create the conditions for innovation of markets, networks and services and the technologies which will be needed to support them, without forcing efforts down one particular route. Baker *et al.* sum up many of the arguments that underlie the need for a change in the regulatory framework of the UK ESI if greater levels of innovation are to be stimulated, highlighting the need for reform across network and market regulation, in dispatch and balancing and in terms of demand response (Baker *et al.*, 2010).

Ofgem acknowledges the need for greater levels of innovation across the ESI and is leading in switching network regulation from the RPI-X system to RIIO while working in partnership with the Government on a new programme of Electricity Market Reform (EMR).

The rest of this section will consider the current shape of UK electricity regulation and the impacts and limitations on the delivery of smarter grid operation. It will discuss the scope of innovation in the different elements of the ESI and the limits of same; describe recent efforts to broaden the scope of regulated utilities to innovate their networks as well as the need to develop policy which will allow for the ESI to deliver on the wide range of challenges it faces relating to cost, the environment, security and reliability of supply and fuel poverty.

Innovation and Distribution Networks

Since privatisation Great Britain has had fourteen distribution networks, while these were initially owned by fourteen separate companies, they are now operated by seven companies who act as distribution network operators (DNOs). The DNOs are privatised companies with shareholders but are currently very limited in the ways they may achieve revenues. There have been a number of changes to the limitations on how DNOs can earn a return and a process is currently underway which will be the biggest change since privatisation.

Ofgem characterises itself as technology neutral and as declining to select a particular technology to achieve a particular goal, rather it prefers a market system which allows companies to bring their own efforts to innovation. This is fine in theory but in practice it tends to mean that DNOs favour established technologies, and the status quo is preserved. The regulatory system for networks has tended to incentivise small incremental change and has not allowed scope for changes to the system such as movement to, for example, two way system flow of power, more active network management and smart grids. Thus the current system strongly discourages access to the long-term benefits to the consumer that might accrue from these systemic changes.

Historically, the income of a DNO has been linked to the expenditure it is allowed by the regulator to invest in its network. This has been set every five years in a distribution price control review (DPCR), the latest, DPCR5 runs from 2010-2015 and following a review (known as RPI-X@20) the current RPI-X system will be replaced with RIIO (Ofgem, 2010c). Determination of allowed revenue is currently based on a number of ‘building blocks’:

- **Operational Expenditure**: An assessment of forecasts of future operational expenditure (opex) based on data submitted by the DNOs about projected spending over the five years of the DPCR, use of historic intra-company comparison of opex and benchmarking analysis. As a result of this analysis, a 1.5% reduction in underlying efficient costs was assumed.
- **Capital expenditure (capex)**: An assessment of future capital expenditure (capex) was carried out using company forecasts of Load Related Expenditure (LRE) and Non Load Related Expenditure (NLRE) as well as comparisons of this against previous spend, future spend given likely load growth and asset age. On the basis of this analysis, allowances of £5,215 million were included within the price control for capex as compared with an overall DNO forecast of £5,852 million at the beginning of the process. Incentives to improve capex efficiency were introduced under DPCR4, in the form of the IQI and associated capex rolling incentive.
- **Depreciation**: Under DPCR4 an allowance was incorporated for straight line depreciation of post-vesting assets. However, Ofgem recognised that some of the

DNOs had seen a large reduction in their depreciation allowances during DPCR3 as vesting assets had become fully depreciated (the depreciation 'cliff-face'). In light of the fact that most of the DNOs would see vesting assets fully depreciated during DPCR4, a smoothing adjustment was applied. Under this adjustment mechanism, new asset lives were reduced from 33 to 20 years with a 15 year smoothing period used for assets that had been assigned a 33 year asset life to allow these to be depreciated over a 20 year period. The exceptions to the application of these provisions were SP Distribution and SSE Hydro where vesting assets were calculated on a longer asset life and therefore these DNOs would still have allowances for the depreciation of pre-vesting assets during DPCR4. Three of the DNOs had also previously had this methodology applied as part of DPCR3.

- **Regulatory Asset Value (RAV)**: The RAVs for each of the DNOs at the time of privatisation were determined as part of DPCR1. These are adjusted at each price control period to reflect actual capex undertaken during the control, allowing for depreciation and adjusting for inflation. Actual capex is based upon figures from the first four years of the price control period and projections of spend in the final year of the control. The RAV is also rolled forward using forecasts levels for the next price control period.
- **Weighted Average Cost of Capital (WACC)**: As part of DPCR4 a “Vanilla” WACC32 return on the RAV was used and this was set at 5.5% which was equivalent to a 6.9%

pre-tax level and therefore consistent with the previous levels of cost of capital set at around 6.5-7%. Notional gearing was assumed to be at 57.5%.

Source: (Ofgem, 2009)

The model for actual calculation is complex but Ofgem have provided a visual guide to the basic concepts which underlie the calculations, see Figure 2.4.

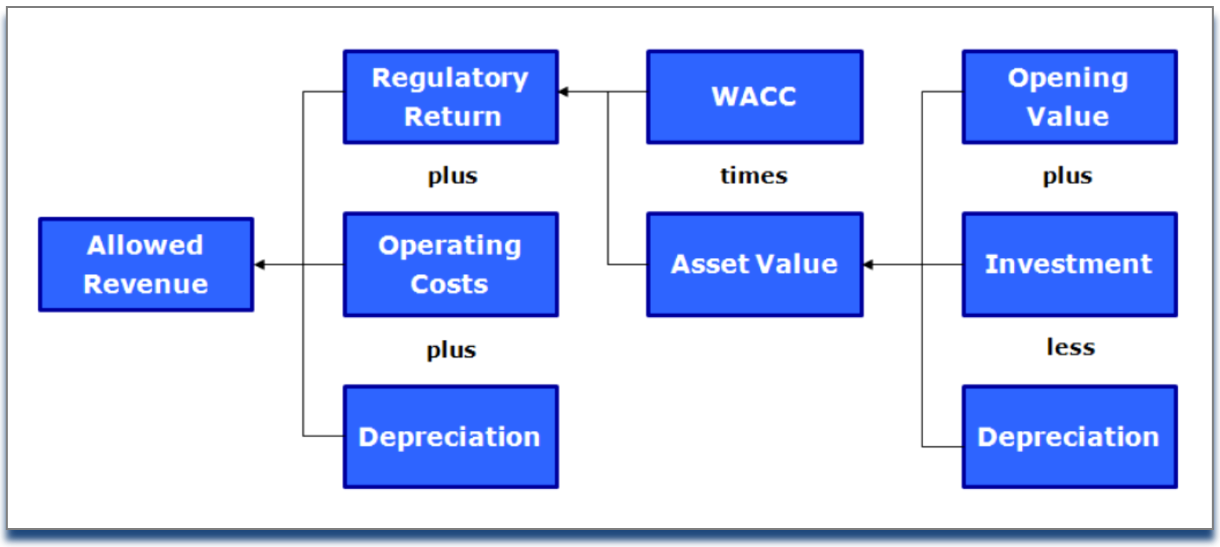


Figure 2.4: Stylised Building Block Representation of RPI-X

RPI-X is a price cap approach to regulation which limits price increases to the rate of inflation (Retail Price Index) minus a value X. The value of X is determined every five years in the UK DPCR system and reflects productivity gains as well as proving incentives for further productivity gains by incentivising DNOs to bring down costs in order to provide a return. This price cap is devised for each year of the price review and turned into a Distribution Use of System (DUoS) charge for different customers and voltages. DNO revenue is based on what the regulator allows them to pass on to consumers, thus creating a distinction between allowable and non-allowable expenditure. The DNO will avoid expenditure not likely to be allowed since it has no way to recoup these funds. Changing what is and is not allowed modifies the incentives for the DNO and thus its behaviour. The degree to which incentives have been changed for DNO s has historically been limited but this began to change with initiatives such as Registered Power Zones and the Innovation Funding Incentive, has changed further with the introduction of the Low Carbon Network Fund, and seems likely to continue to change significantly with RIIO.

The different elements of RPI-X have expanded since first introduced, but the underlying goal has effectively remained the same, that RPI-X would provide a stimulus for improved efficiency in network operation and thus achieve cost reduction which could be passed to the consumer. By setting X such that companies can only remain profitable by improving efficiency continuously then prices are continually pushed down.

DNOs have to comply with a number of performance measurements or are penalised. Once these are met, the DNOs will revert to the fundamental economic drivers of the price control in order to maximise their return. DNOs thus have a number of key incentives and management drivers which shape their behaviour.

1. A focus on capital asset expenditure since this will expand the Regulatory Asset Value (RAV) of the DNO.
2. An incentive to minimise operational expenditure. This incentive is significant here since it will tend to undermine substantial innovation, and confine DNO behaviour to small changes within the existing system rather than offer any potential for overall system change. This also means any activities heavily weighted towards operational expenditure are disincentivised
3. RPI-X regulation which is a blunt instrument to reduce costs rather than to provide incentives to meet performance standards.

Investment in the Networks

The network functions of the ESI are perceived as a low risk investment opportunity and are regulated to provide a low return.

Stimulating Network Innovation

Ofgem has begun to take action to address the problem of innovation on the networks. The regulator introduced the Innovation Funding Incentive (IFI), Registered Power Zones (RPZ) in 2005 and more recently the Low Carbon Networks Fund (LCNF) has begun to be brought into use. Each programme has been introduced with the intention of opening up the scope of the distribution networks

Registered Power Zones and the Innovation Funding Incentive

Both the IFI and RPZ were initially proposed by Ofgem in March 2002 and then introduced as part of DPCR4 from 2005. Both are intended to "apply technical innovation in the way they pursue investment in and operation of their networks" (Ofgem, 2005). Power Zones were "envisaged to be a defined electrical, or perhaps geographic, area that is proposed by the DNO and forms a 'bounded network'. Within a power zone, a DNO could apply new technologies, technical solutions and operating practices, as well as pilot new commercial structures to exploit the possibilities for DG to improve quality of supply, reduce losses, minimise constraints to generator operation, and ultimately enable the network to be run at a lower overall cost. Power zones could also provide a framework in which Ofgem could encourage, in a controlled manner, DNO initiatives in relation to distributed generation by specific regulatory treatment such as appropriate treatment of costs that are incurred and other incentives." The focus of RPZs was at the point of connection between a generator and the distribution network, with the aim of providing innovative solutions which would benefit both the generator and, in the long-term, the consumer through greater competition and potentially reduced costs. DNOs were incentivised to take part in the RPZ programme via an incentive of £3/kW/year and an addition to their allowed revenue of up to £0.5m per year.

At the end of 2008-9, three DNOs were operating one RPZ project each (Ofgem, 2010a). The RPZs have been superseded by the Low Carbon Networks Fund from 2010. The IFI represented Ofgem's response to the consistent decline from 1990 onwards (approaching zero) in investment in research and development by DNOs. It allows a DNO to pass costs of eligible IFI projects to customers (declining from 90% to 70% from 2005 to 2010). Ofgem agreed in February 2006 to extend the IFI scheme to the end of DPCR5 (2015) with the aim of giving the DNOs the confidence to build their Research and Development portfolios. Eligible IFI projects are defined as those "designed to enhance the technical development of distribution networks and can embrace asset management from design through to construction, commissioning, operation, maintenance and decommissioning" (Ofgem, 2010a).

The introduction of RPZ and IFI can be regarded as the first significant step taken by Ofgem in acknowledging and responding to the need to adapt the regulatory framework for networks; both to fit within an ESI with higher levels of distributed and potentially intermittent generation, and as a precursor to the adoption of greater levels of smart metering and other smart energy technology and demand response. Ofgem recognised that the level of risk associated with innovation regarding distribution networks did not fit with the profile of investment typified by the sector. The regulator sought to enable the DNOs to secure greater reward against the risk inherent in greater levels of research, development and innovation, with the eventual aim of learning lessons under both programmes which could be rolled out more widely across the network (Ofgem, 2005).

Ofgem records the total new present value of IFI portfolios for the DNOs at £67m at the end of 2008–9, suggesting they have had value in advancing R&D expenditure (Ofgem, 2010a).

It can be seen as an initial response to the need to incentivise efficient management of renewal and expansion of network assets and to enable wider provision of DG connectivity across multiple distribution voltage levels.

The Low Carbon Networks Fund

The Low Carbon Networks Fund (LCNF) was introduced in 2010 as part of DPCR5. The goal is to further support DNOs in investigating and deepening their knowledge and experience in the operation of networks as they evolve to take into account changes relating to security of supply and reduced carbon emissions (Ofgem, 2011b).

The LCNF supports two tiers of projects; smaller projects in Tier 1 and larger 'flagship' projects in Tier 2. Tier 1 projects should last no longer than three years and must involve the trialling on the Distribution System of at least one of the following:

- A specific piece of new (i.e. unproven in GB) equipment (including control and communications systems and software) that has a Direct Impact on the Distribution System.

- A novel arrangement or application of existing Distribution System equipment (including control and communications systems and software).
- A novel operational practice directly related to the operation of the Distribution System, or
- A novel commercial arrangement with a Distribution System User.

(Ofgem, 2011b)

To qualify, a project must also accelerate the move to a low carbon economy, have the potential to offer financial benefits to consumers, directly impact on the DNO's operations; generate new knowledge which can be disseminated amongst the other DNOs; apply methods which are at the trial stage and which do not duplicate previous work (Ofgem, 2011b).

Tier 2 projects are larger though subject to many of the same criteria. DNOs are limited to two Tier 2 projects each and all are subject to approval via a screening process and then evaluation by an expert panel. Ofgem states a wish to see greater flexibility in tier 2 projects. They see second Tier Projects as providing an opportunity for DNOs to engage with stakeholders including generators, consumers, supply companies to explore the interactions required with them to facilitate the transition to a low carbon economy (Ofgem, 2011b).

It should be noted that Ofgem does not hold funding for the projects; rather, approved expenditure is on an allowed basis and can be passed on to consumers. DNOs are expected to provide at least 10% of project funds themselves.

The LCNF has so far led to the establishment of a number of projects including the use of data from smart meters, the use of energy storage and the impacts of electric car usage on the network. Many of these projects can be regarded as likely to provide outputs which will assist in the understanding the challenges of moving to greater adoption of smart grids.

Low Carbon Investment Fund

The Low Carbon Investment Fund (LCIF) is operated by DECC and provides grants to push low carbon technologies forward with the aim of eventual commercial exploitation. The LCIF Smart Grid Demonstration Capital Grant Programme is an element of the LCIF aiming to facilitate the development of technologies relevant to the supply chains of smart grid development (DECC, 2009a). Grants up to £6m were made available though only £2.8m was taken up. Grants were available up to 25% of the total capital cost, with uplifts for collaboration and for small and medium sized enterprises.

RIIO: Revenue = Incentives + Innovation + Outputs

The instruments noted above are essentially concerned with stimulating R&D, and while they might be seen as natural precursors to change, the shift to RIIO from 2015 represents a much bigger step towards changing the fundamentals of how the networks are incentivised and thus operate. Ofgem carried out substantial consultation leading it to make the following conclusions concerning the replacement for the RPI-X system.

That the RIIO mechanism would be

- Outputs-led, making it clear to network operators what would be expected in terms of delivering safe and reliable services, on a non-discriminatory and with timely connection and access terms, customer satisfaction, limited impact on the environment and delivery of social obligations.
- Ex-ante control: an upfront price control, incorporating a return on the regulatory asset value and inflation indexation. RPI will be retained as the inflation index, though a switch to CPI will be further considered in the event of the introduction of any later price controls for gas and electricity transmission and distribution.
- The length of price controls will increase to eight years and this will be reconsidered in each price control review. A mechanism to deal with uncertainty will be available to assist with the raising of network financing where this is appropriate.
- Ofgem will adopt a transparent and proportionate approach to assessing the price control package, with the intensity and timescale of assessment reflecting the quality of an individual company's business plan and its record for efficient output delivery. A shortened price control process is possible.
- Ofgem may require market testing of proposals prior to approval of business plans. They may also involve third parties in financing major projects as appropriate.

- Ofgem will publish clear and transparent guidance as to the application of penalties to companies which consistently do not deliver on their commitments. Incentives will be "transparent, upfront, symmetric efficiency incentive rates for under- and overspend. Incentives will be calibrated to ensure they provide long-term value for money."
- Ofgem will publish principles for setting a WACC based allowable return which reflects long-term cash flow risk for a business.
- Ofgem will institute a time-limited innovation stimulus package which will be open to network operators and other companies to support network innovation projects. This package will include substantial rewards for companies that "successfully implement new commercial and charging arrangements".

Source: (Ofgem, 2010d)

Ofgem believes that this structure will allow clear incentives for the achievement of the goals of an environmentally sustainable energy sector without imposing an excessive cost burden on the consumers. It has included scope for changes should it become apparent that the model is not delivering on the desired goals. Despite this, RIIO is an ambitious and complex new model and is untested in terms of how it will achieve its goals and, perhaps most notably, how the network operators will respond to the incentives it will provide and how flexible these will be in response to network operator and investor behaviour which will not provide the desired outcomes.

Ofgem has made it clear that the IFI and LCNF initiatives will be rolled into and continue under RIIO. RIIO will also build additional programmes to stimulate innovation, the Network Innovation Competition and the Innovation Allowance.

Müller characterises the shift to RIIO as a pioneering move away from efficiency incentives and towards a “holistic innovation and output-oriented approach with a forward looking, long-term value for money perspective”, and offering the potential to regulatory stimulation of a more dynamic approach to incentivising decarbonisation across the supply framework. The long-term perspective is particularly praised, while raising concerns about the high level of regulatory planning and oversight inherent in the model (Müller 2011).

Network Innovation Competition

The Network Innovation Competition (NIC) will be introduced in the electricity transmission network price control review from 2013. It is intended to build on the work of the LCNF and the current LCNF will be folded into a new NIC to provide a direct equivalent for innovation of electricity distribution networks as well as transmission networks from the end of the current

DPCR period in 2015. The NIC will borrow much of the process of the LCNF in terms of assessment of project potential.

The NIC is essentially a competition to encourage innovation; £240 million will be made available for innovation on the electricity transmission networks over the eight year period of the price control review, and up to 90% of funding may be claimed. Currently the NIC will allow non-network companies to collaborate with network companies to receive funds, though the introduction of an ‘innovation licence’ which would allow independent work by non-network companies has been rejected (Ofgem, 2011a).

Innovation Allowance

The Innovation Allowance (IA) is a development of the IFI and is intended to stimulate network innovation at the smaller scale. As with the NIC, it is intended that it will apply from 2013 for the electricity transmission network and then be wrapped into the distribution price control review from 2015. As with the IFI spending would be capped to a small fraction of network operator revenue, with 0.5% and 1% of allowed revenues as the current proposal – a sliding scale will apply to different network operators. Ofgem has also proposed a ‘sliding cap’ on the amount of funding per project, dependent on the size of the project, this will vary between 5% and 10% (Ofgem, 2012).

Market Design and Smart Grid Development

Baker *et al.* (2010) emphasise that the infrastructure of the UK ESI and the way that the electricity market is constructed has been based around centralised generation. The mechanisms for physical delivery are rooted in the use of large-scale, highly controllable plant with high levels of availability. The transmission network was designed to be capable of delivering the output of all generating capacity and had few constraints as a result. The pre-privatisation ESI had a high capacity margin which has been slowly whittled away as demand rises, plants become obsolete and new plant has been economically difficult to develop. They note that since the design of the market for trading in electricity means system congestion, costs have been socialised while long-term investment costs in the transmission network have been largely predictable and determined on an ex-ante basis with a focus on improving spending efficiency and cost effectiveness of allowed expenditure.

They suggest that an ESI requiring low carbon emissions as the UK aims to achieve, will need to deal with large volumes of intermittent RES-E, using fossil fuels only as a last resort.

Baker *et al.* consider the need for a market sector to evolve to meet the needs of a low-carbon economy. An incremental approach to changing from the current system is suggested and informs their consideration.

Baker *et al.* (2010) consider the ongoing performance and potential evolution of the current 'energy-only' market which applies within the UK ESI and the challenges that are likely to develop in light of the expected changes to that market, along with their implications for maintaining sufficient margin to meet peak demands. They consider a number of potential market changes, including Capacity Markets, though their report predates the decision by the UK government to select this as the option for ensuring sufficient investment in generation.

Dispatch and Balancing

The current GB market for electricity, with its mechanism for bilateral trading between generators and suppliers does not attempt to optimise for dispatch. Rather, agreed trades are notified to the system operator and they must provide any balancing within the system. Baker *et al.* (2010) note significant potential for lack of optimisation stemming from this system and the internal trading between companies with trading and generation arms it creates. They also note the potential for system losses it creates, potentially adding 3-4% to generation requirements over an optimised system.

Organisations working to support Smart Grid implementation in the UK

A number of organisations are active in relation to smart grids in the UK, representing different stakeholders. The most active in the policy process are considered here.

The *Electricity Network Strategy Group* (ENSG) is a high-level stakeholder consultation group facilitated by DECC and Ofgem with the goal of bringing together representatives of energy companies, trade associations and the devolved administrations. Broadly, ENSG's aim is to identify and co-ordinate work which addresses the key strategic issues likely to affect the electricity networks in the transition to a low-carbon future. The ENSG have published a number of papers addressing network issues relating to the future of UK electricity networks and their regulation, and by extension the role of smart grids within this. They have published and updated a report concerning the future of the transmission network in a number of scenarios rooted in the achievement of renewable energy targets as set by the UK Government and the devolved administrations (ENSG, 2009).

DECC has also worked with Ofgem to institute and jointly facilitate the *Smart Grid Forum* (SGF), this extends the work carried out by the ENSG. Its brief is to identify the challenges and barriers to the adoption of smarter electricity networks, to provide guidance to DECC and Ofgem as to identifying and overcoming these, work with industry and other stakeholders to facilitate deployment and track efforts to advance smart grids outside the UK. Its membership draws largely on the energy utilities and industry representatives with some involvement from academia and consumer representation. Despite being formed in early 2011 the SGF has already produced a number of interesting documents.

The SGF commissioned ‘How to deliver smarter grids in GB’ (Frontier Economics, 2011; Smart Grid Forum, 2011) to set out the current UK policy landscape concerning smart grids and attendant technologies. The SGF has used this as a starting point to address five work streams (WS) with which it intends to engage stakeholders.

- WS1 – Assumptions and scenarios: Led by DECC, this WS will establish the assumptions and scenarios necessary for network companies to produce business plans consistent with DECC’s low carbon transition.
- WS2 – Evaluation Framework: Led by Ofgem, this WS will develop an evaluation framework to assess alternative network development options to inform policy decisions related to smart grids.
- WS3 – Developing Networks for Low Carbon: Led by the DNOs, WS3 will assess the network impacts of the assumptions and scenarios from WS1.
- WS4 – Closing Doors: Multiple stakeholder policy assessment to identify risks to smart grid development.
- WS5 – Ways of Working: Strategies for the SGF to best pursue its objectives and communicate effectively with stakeholders.

Source: (Smart Grid Forum, 2011)

The SGF will carry out consultations regarding the content and goals of the work streams, and some have already been carried out. The EMR White Paper makes it clear that the SGF will lead in developing Government strategy relating to smart grids, in establishing shared assumptions with the involved utilities and to address future challenges regarding the electricity network (DECC, 2011d).

The UK government and the SGF has also agreed to work with *SmartGrid GB*, a new industry led initiative to increase understanding of what a smart grid is and the challenges and benefits of moving towards greater use of smart grids, to drive forward adoption of smart grids and to facilitate action amongst stakeholders. Its members are drawn from multiple sectors, including energy utilities, ICT providers and others such as Consumer Focus with an interest in different elements that will inform future smart grids development in the UK (SmartGrid GB, 2011).

Consumer Focus has a legally mandated consumer protection role concerning energy supply in the UK which includes consideration of any issues arising from the development of smart grids. Their activities are described below.

Consumer Protection and Smart Energy Delivery

Consumer issues related to the UK ESI were separated from the regulator by the Utilities Act 2000, when responsibility for consumer representation, complaint resolution andinformation provision was given over to the consumer protection body Energywatch.

Energywatch's responsibilities were then absorbed into Consumer Focus following its formation in October 2008. Consumer Focus is funded by the Department of Business and Innovation (BIS) and by utility licence fees and has significant statutory powers relating to consumer representation including "the right to investigate **any** consumer complaint if they are of wider interest, the right to open up information from providers, the power to conduct research and the ability to make an official super-complaint about failing services." However, following the 2010 change in Government Consumer Focus is likely to be abolished following a public consultation, with some powers handed over to other bodies, probably from spring 2013. While some of the responsibilities of Consumer Focus will pass to Citizens Advice it is not clear how this will impact on consumer representation on issues where development of new technologies and applications may imply significant impact on consumers, as with medium- and long-term rolling out of smart meters and smarter grid technology.

Consumer Focus has produced a number of reports concerning smart meters and displays and with a focus on the need to protect the interests of consumers in regard of the cost of adopting meters and displays and whether they are likely to represent value for money. Consumer Focus has produced a number of publications considering the value of smart meters in energy saving, in fuel poverty reduction and in relation to demand management. They have also expressed concern about data protection relating to smart metering and its future management in the context of smart metering.

- Many of the changes brought about by the introduction of smart grids and attendant technologies will impact on consumers. These may include, with different levels of likelihood. The introduction of smart meters into consumer property may occur with different levels of information
- The transmission of data and the ownership of that data by private partners
- Greater levels of demand responsiveness, with different levels of automation of consumer usage. There is considerable potential for variance in accessing different tariff rates, for example relating to the consumer's position on the grid. There is considerable potential for increased complexity.

These will have potentially significant implications for consumers, and issues relating to privacy, data protection and pricing may affect some groups more than others, for example vulnerable energy consumers.

2.4 Technical aspects

Finally, technical aspects are clearly as important as the previously explored three aspects. In this section we will explore some of the possibilities and limitations, necessary components and specifications that will allow further “smartening” of the electricity grid.

According to DECC building a “smarter grid” is seen as an incremental process of applying information and communication technologies (ICTs) to the electricity system which allows power network infrastructure to be operated in a more dynamic, efficient and reliable way than the “passive” operational approach. In future, many consumers will also be producers and networks need to manage bidirectional power flow without damage to equipment of disruption to supply (DECC, 2009e).

At the same time Smart Grid implementation and development will be exposed to a dynamic threat model where threats are constantly changing and unpredictable (Tritschler and Mackay, 2011). ICT security is seen as a critical attribute for SG implementation and operation. The “UK Smart Grid Cyber Security” report (Tritschler and Mackay, 2011) prepared by the Energy Networks Association (ENA) reviews current standards and guidelines for smart cyber security including national and regional considerations.

Future Smart Grid ICT Infrastructure to Support Smart Grid Interoperability

At the national level governance arrangements for IT systems (including communication) and SCADA equipment are well established and robust. These practices are less evident for remote equipment; including substation installed Remote Terminal Units (RTU) which provides potential entry points to the networks and systems upstream. Poor governance at this level can lead to opportunity for intentional network disruption. At present there is no single role which is responsible for cyber security across all elements of the operational network management systems. At the National Level, cyber security should be considered from a collaborative national perspective industry wide, developing and maintaining a national level risk assessment process (Tritschler and Mackay, 2011).

At the regional level, each DNO is responsible for deployment of its own SG solutions, including communication infrastructure posing a grated challenge to the coordination of SG cyber security efforts. Therefore, ENA proposes the development of an Operational Security Management system to bring cyber security under the explicit control of management considering a Technology Change Management strategy using risk assessment approaches (Tritschler and Mackay, 2011). Smart metering is seen as a key component of SG architecture to facilitate secure participation of the domestic, industrial and commercial consumer.

Interoperability and Standards

A number of recognised core standards for the Smart Grid focus on the information models and protocols that are important for efficient and reliable grid operations, as well as cyber security. These standards are produced by the International Electrotechnical Commission (IEC). The IEC Smart Grid Strategic Group developed a framework that included standards to achieve interoperability of smart grid devices. Interoperability – the capacity for devices from various manufacturers to work together – is vital to the realization of a network-based smart grid, and the key to interoperability is standards (IEC, 2010b). The entire smart grid proposition is predicated on open communications between the “smart” devices using common protocols. IEC has compiled a list of around 300 smart grid standards. The full and updated list can be seen at (IEC, n.d a). In that list, the standards are sorted according to their perceived relevance – core, high, low, and medium – to the functioning and designing of Smart Grids. The “foundational” sets of standards for smart grid interoperability and cyber security are:

Standard	Details
IEC 60870 -6	Facilitating exchanges of information between control centres (IEC, 2005a)
IEC 61970/61968	61968 Providing a Common Information Model (CIM), necessary for exchanges of data between devices and

	networks (IEC, 2003a; IEC, 2007e)
IEC 61850	Facilitating substation automation and communication as well as interoperability through a common data format (IEC, 2004)
IEC 62357	Seamless Integration Reference Architecture (IEC, 2003b)
IEC 60870	Transport protocols (IEC, 2005b)
IEC 62325	Market Communications using CIM (IEC, 2005c; IEC, 2005d; IEC, 2005e)
IEC 61850	Communications, Distributed Energy Resources (IEC2009a; IEC, 2013)
IEC 61400	Communications for monitoring and control of wind power plants (IEC 2005f; IEC, 2006a; IEC, 2009b; and IEC, 2006b)
IEC 62351	Security for Smart Grid, Addressing the cyber security of the communication protocols defined by the preceding IEC standards. Security is generally described in terms of availability, integrity, and confidentiality. (IEC 2007a; IEC 2008; IEC 2007b; IEC 2007c; IEC 2009c; IEC 2007d; IEC 2010c)
EN 50523	Home Appliances (British Standards Institute, 2009)

Table 2.2: IEC Common Information Model and associated Information Model standards

European standardisation organisation bodies are working towards a common European standard (European Commission, 2010). The standardisation bodies involved are: (i) Comité Européen de Normalisation (CEN), (ii) Comité Européen de Normalisation Électrotechnique (CENELEC), and (iii) the European Telecommunications Standards Institute (ETSI). The common European standard is expected to deal with issues regarding safety, interoperability and smart charging requirements (European Commission, 2010).

IEC Common Information Model (CIM)

The CIM comprises a set of International Electrotechnical Commission (IEC) standards (IEC, 2010d; IEC, 2010e; IEC, 2005g; IEC 2009d; IEC n.d d) whose origins were in work sponsored by EPRI for the vendor-agnostic exchange of data between power utility control systems (EPRI, 1996). These standards, which are now managed by IEC Working Groups described in Fig. 1, provide a taxonomic semantic reference 'framework' of UML class objects describing the components of power utility networks and their functions to a high degree of granularity. The relationships between class objects are defined to provide a standardised object-oriented modelling architecture. This is being harmonised at its periphery with other existing information models, such as the IEC 61850, substation automation model standard, to provide an integrated standards framework supporting smart grid interoperability (NIST, 2010a). The structure of the CIM is not rigid as the ontology of class objects are designed to be both 'extensible' (ie. when new objects not available within the standard set are needed, they can be added), and 'scalable', such as when a subset of the standard reference classes (called a profile) are sufficient to model a given entity in a particular *context* , after which the rest of the reference model can be ignored. As it is canonical in its design, 'packages' of UML classes are integrated with the core standard as further use cases for information exchanges are modelled (McMorran and Ault *et al.*, 2008; Podmore and Robinson, 2011; Britton, 2011).

Working Group	Standard	Details
10	IEC 61850	Substation automation and field devices
13	IEC 61970-301	Energy Management System Interfaces
14	IEC 61968-11	System Interfaces for Distribution management
15	IEC 62351	Data & communication security
16	IEC 62325	CIM market extensions for Europe & N. America
17	IEC 61850-7-420	Communication systems for distributed energy resources
18	IEC 61850-7-410	Communications systems for hydroelectric

		plant
19		Harmonisation of WG13 & WG14 efforts

Table 2.3: EC Common Information Model and associated Information Model Working

As the scope of CIM has extended from its origins as an Energy Management System interface protocol it is, according to the National Institute of Standards and Technology (NIST), one of the five core sets of smart grid interoperability enablement standards (NIST, 2010b).

As a common information model, the CIM offers a reference as well as Application Programming Interfaces (APIs) for power utilities to advance their own level of information integration (Cao and Zhou *et al.*,2010; Ranzhe, 2008; Becker and Saxton, 2008; Vujovic and Robinson, 2009; Ilich and Riddles *et al.*,2008; Hargreaves and Taylor *et al.*, 2011). Several challenges encountered in this process are addressed by Khare, *et al.*,(2011) in 'Patterns and Practices for CIM Applications'. Driven by the combination of greater reliance on renewable energy sources and the deregulation of increasingly interconnected electricity markets, the level of data associated with smart grid Advanced Metering Infrastructures (AMIs) and unprecedented levels of input from other data sources (such as meteorology and market systems) implementation of a utility common information model based on the IEC CIM will need to support power utility intra- and interoperability within the smart grid to ensure technical compatibility (Hargreaves and Taylor *et al.*, 2011; Tolk, 2010; Ivanov and Chury, 2009; Lambert and Fremont *et al.*, 2008).

Situational awareness

The need for greater situational awareness and risk management by power utilities will be required to manage the levels of variability imparted to the grid by weather and market-dependent supply and demand as well as an increasingly complex meshing of power-flows, as generation moves from the traditional radial model to one which is embedded and peripheral. As such, with increased modelling and data flows, one may regard the future smart grid as a cyber-physical entity requiring the optimal processing of huge amounts of data to run securely (Banerjee and Venkatasubramanian *et al.*, 2012). The opportunity to move away from underutilised and expensive utility-owned computational services to novel processing and storage architectures such as cloud computing environments has been recognised as a means to meeting smart grid information management needs (Hardin, 2009; Ling and Shuangbao *et al.*, 2011; Liang and Xiuqing, 2011).

Cloud computing architectures provide attractive attributes to the smart grid information processing use case, including computation and storage elasticity, metered usage, the opportunity to select a number of different operational models due to the layering of services (IaaS, PaaS, SaaS etc.) and potential to share resources (private, community hybrid, etc.) However the critical issues of security and privacy which are so important power utility operations are not generally addressed to the requisite degree in commercial cloud operations such as Amazon EC2, Google AppEngine etc (Cachin and Schunter, 2011).

Secure private cloud architectures which are suitable for power utility use, and to which provenance of storage and virtualisation technologies can be remotely attested, are receiving greater attention (Ling and Yanxiang *et al.*, 2011; Satish, 2011; Abbadi, 2011; Atmaja and Fitriana, 2011; Khan and Rehman *et al.*, 2011). However, both the security and resilience aspects of cloud services need to be considered, although they could be addressed in a conventional back-up model involving 'redundant' cloud architectures. Beyond that, there is scope for enabling more utility data processing services in the cloud to both share private data (say merging the network models of Distribution Network Operators and Transmission Operator) and to perform common operational tasks, such as data standardisation and CIM validation (Wallom and Turilli *et al.*, 2011).

Applications of PMUs and Synchrophasors to Enable Smart Grids

Synchronised Phasor Measurement Units (PMUs) calculate, amongst other information, positive-sequence voltages (magnitude and phase) at typical rates equivalent to the power systems fundamental frequency (50/60Hz). These high-resolution measurements are making it possible to track dynamic changes on the grid and visualise the changing network state in real-time.

Such devices enable wide area monitoring system (WAMS) provision and are therefore opening up a number of SG applications that will be necessary when operating future power networks. One clear advantage of the technology over traditional SCADA monitoring is in relation to post-event analysis, through the ability to very quickly and conveniently collate all the synchronised data, thus facilitating investigation into the cause of system incidents as they 'ripple' through the transmission networks (Ashton and Taylor *et al.*, 2011). This can lead to identifying both areas of weakness in the networks and key areas for reinforcements.

The synchrophasor positive sequence measurements are considered to represent the state vector of the power system, fundamental in all analysis and so it is preferable to use these directly obtained results to exclusively monitor the state of the power system (Phadke and Thorp *et al.*, 1986) over the nonlinear algorithms typically employed in the State Estimation (SE) process of Energy Management Systems (EMS). The existing SE process is very prone to errors and is typically only run every 5-10 minutes making the assumption that the network is static over this period.

Utilising PMUs for this application implies more of a state determination than estimation but, it is not a straightforward process, as it is estimated that to achieve full observability, PMUs need to be installed at approximately 1/3 of all system buses (Baldwin and Mili *et al.*, 1993) and at present the numbers of installed PMUs are some way from this.

In order to minimise the error to SE, the appropriate buses for PMUs (Fish and Chowdhury *et al.*, 2011; Gou, 2008) need consideration but, due to the limited numbers, is at present academic. The majority of practical applications are focused on combining the synchrophasor information with that of existing SCADA data (Skok and Pavic *et al.*, 2008) to improve the accuracy of the SE process, this can shorten the computation time and increase precision. This is not without its challenges, such as preparation of the PMU data and tuning of data weightings in line with existing measurements. Thought also needs to be given to the accuracy (weighting) of the PMU measurements and at what instance in time to sample the PMU data.

Recognising that wide-area monitoring and control are one of the key aspects of the Smart Grid, power utilities globally are predominantly starting to use PMUs to improve situational awareness through online stability monitoring (Ashton and Taylor *et al.*, 2011; Leirbukt and Gjerde *et al.*, 2006; Ota and Hashiguchi *et al.*, 2007) and real time data visualisation (Overbye and Weber, 2000), noting the importance of displaying the information in the most appropriate fashion.

NAPSI, The North American SynchroPhasor Initiative, which aims to improve power system reliability and visibility through wide area measurement and control (North American SynchroPhasor Initiative, n.d), are working with the Department of Energy and the network operators in America to facilitate the integration of PMU based applications across the continent. FNET a pioneering WAMS project (Yingchen and Markham *et al.*, 2010) is serving the entire North American power grid providing situational awareness and accurate event location estimation.

Whilst the numbers of PMUs are rapidly increasing globally, the installation process is dependent on the network outage programs. However, a number of WAMS are emerging at the domestic supply level (Terzija and Regulski *et al.*, 2011; Grady and Costello, 2010). The ease of installation over the substation, offering up a great advantage and the ability to monitor transmission incidents at this level, is proving to be extremely valuable.

On-line Transmission System Stability Control Systems

After the blackouts that affected US, UK and mainland Europe power grids in 2003 and 2004, more attention is now being focused on maintaining the highest level of reliability and security in the operation of power systems. In addition, the electricity industry now clearly understands the need for continuously monitoring and updating the loadability limit, in order to maintain the reliability and security of power systems. Therefore more and more control centres are considering deploying and adopting novel smart grid tools to perform on line stability assessment.

The three main requirements for on-line stability control systems are as follows (Savulescu, 2009):

- Execute fast stability calculations with data from real time SCADA/EMS;
- Complete the execution of the stability application within the time span of the real time network analysis sequences, which means before the next run of the state estimator, stability computation results are ready to be displayed;
- Present the results in a format that facilitate the quick and reliable on-line decision making.

Akira and Masato reported the operation of On-line Transient Stability Control (TSC) system in CEPCO (Chubu Electric Power Co.Inc) in (Takeuchi and Niwa *et al.*, 2006). Japan's power system consists of two separate frequency regions: a 50 Hz and 60 HZ region. The two regions are dc-linked by frequency converter stations, which are located at the eastern end of the 60 Hz region, the electric power system of CEPCO located at the end of the extended 60 Hz system, stretching from east to west . Therefore this area has always had stability issues. CEPCO implemented the on-line TSC system to tackle the problems of system stability. Principally, the on-line TSC system is designed to collect system information from the power supply information network, performing stability calculations using the obtained system data and selecting generators to be shed in response to the current system conditions. Evaluation of the performance of the on-line TSC system during the period from 2002 to 2004 indicated that employing the system resulted in a stable supply of electric power and brought economic benefits due to the improved TTC (total transfer capability) (Takeuchi and Niwa *et al.*, 2006), these included:

- Improvement of TTC through elimination of transient stability limitations;
- Selectability of ideal power shedding;
- Reliability improved by using different maker systems.

Dacai (2011) reviewed the China Southern power Grid (CSG) defence scheme, designed to protect against large disturbances. CSG is one of the most unique HVAC/HVAC hybrid transmission power grids. The study shows how the multi-layer defence solution applied using the on-line security assessment (DSA) and wide area control system (WACS) were employed to deal with the most common cascading faults in the CSG. These faults included bipolar block of HVDC lines and multi 500kV line or component trip due to inclement weather. The CSG has a reliable DSA with functions of on-line stability assessment, including transient security assessment (TSA)and voltage security assessment (VSA). Thus the emergency control strategy for SPS/SPIS (special protection scheme) can be evaluated. In the second line of defence WACS is used to prevent cascading fault and develop integrated a multi-DC damping system (Dacai, 2011).

On-Line Power System Stability Screening of Practical Power System Models was analysed in Jianzhong and Hsiao-Dong *et al.* (2010). This paper illustrated one practical application of the controlling UEP method and the theory-based BCU method on large-scale power systems with practical data in an on-line environment. In this study TEPCO-BCU was selected as a fast screening tool to improve the performance of the PJM TSA system and also comprehensive evaluation of the TEPCO-BCU package in a real time environment was presented as a transient stability analysis screening tool. This paper looks into the largest practical application of the stability region theory and its estimation in terms of system size. This study confirms that theory-based methods can lead to practical and reliable applications (Jianzhong and Hsiao-Dong *et al.*, 2010).

The other study on TEPCO-BCU (Hsiao-Dong and Jianzhong *et al.*, 2010) represents the largest practical application of the theory of a stability region in terms of the system with 14,000 buses and a total number of 5,293,691 contingencies and over a wide range of operating conditions. The extensive evaluation studies on the 14,000-bus have confirmed that TEPCO-BCU can meet the five requirements of being an ideal dynamic contingency screening tool.

In 2009 significant results regarding on-line transient stability assessment were presented in Soykan and Dag (2009). In their paper, the use of the parallel computing toolbox of Matlab for transient stability assessment was demonstrated. In this regard, IEEE 57 and 118 bus systems were tested with 57 and 56 contingencies respectively. The results of research show that domain decomposition based method for on-line transient stability assessment is quite effective and very user friendly. Because of the decreasing cost of hardware and growing computing power of processors, the parallel programming is the essential way to reveal compute power of computer systems (Soykan and Dag, 2009).

In Du and Niu *et al.* (2007), the relevance vector machine (RVM) for transient stability assessment was presented. This method was tested on a practical power system and compared with the “support vector machine” classifier. The classification performance was evaluated using false discriminate rate. In the paper the main concern of the authors is to find the best structure of the classification model for modelling non-linear dynamic system with measurement error. RVM is not necessary to satisfy Mercer’s condition and as a result selection of kernel functions is beyond the limit of the positive definite continuous symmetric function of support vector machine (SVM). The study showed that the RVM has small model capacity and describes good generalisation to compare with SVM’s in simulations (Du and Niu *et al.*, 2007).

Emerging Standards to Enable Scalable Smart Grid Communications

At high voltage levels, long lines between generators and load centers, new generation capacities from different types of sources, growing interconnection links and ever changing customer behavior, will make current power system analysis and control tools obsolete in the near future.

Smart grid capabilities like wide area monitoring, protection, automation and control (WAMPAC) are designed by integrating special protection schemes (SPSs), remedial action schemes (RASs), emergency control systems (ECSs) and wide area protection schemes. All these types of new applications in smart grids rely on vast networks of intelligent electronic devices (IEDs) that monitor the power system status and act in case of contingencies.

Digital communications between IEDs and protection, monitoring and control functions implemented in them are designed similarly to the ones in traditional substation automation systems, but they have to be adopted for wide-area control. In current power networks, communications between IEDs are achieved through dedicated channels, but there is active migration seen towards Ethernet, with the development of Generic Object-Oriented Substation Event (GOOSE) messaging within the IEC 61850 standard.

IEC 61850 GOOSE messages are exchanged by a publish/subscribe mechanism. The GOOSE messages contain information that allow the receiving device to know that a status has changed and the time of the last status change. All devices sending GOOSE messages continue to send the message with a long cycle time, even if no status/value change occurs. This ensures that devices that have been activated recently will know the current status values of their peer devices. The peer-to-peer communication using GOOSE messages over Ethernet uses multicasting without acknowledgement.

A well documented survey of communication technologies in Smart Grids can be found in Gao and Xiao *et al.* (2012), where networking technologies proposals are investigated with regards to communication/networking architectures, QoS, optimization, and control and management of operations in the Smart Grid. An investigation of capabilities in communication-aided protection schemes with the IEC 61850 standard is presented in Xyngi and Popov (2010), by describing the concept of integrated protection unit and the IEC61850-9-2 process bus concept. It also discusses techniques to encompass intersubstation communications and examines issues that need to be addressed to create a successful, secure and dependable communication network.

A proposal to combine functions of IEC 61850-compliant devices with IEC 61499-compliant "glue logic", using the communication services of IEC 61850-7-2 is presented in Higgins and Vyatkin *et al.* (2011), to enhance the flexibility and adaptability of automation systems, speeding progress toward the realization of the smart grid concept.

Implementations of protection schemes, based on the IEC 61850 standard, are proposed in Ali and Thomas (2011), Apostolov and Vandiver (2011) and Atienza (2010). These papers describe and compare new testing tools for protection schemes based on IEC 61850 with traditional testing techniques. New load shedding and advanced bus transfer applications with IEC 61850 are proposed in Zhao and Sevov *et al.* (2011). A comprehensive performance evaluation of the IEC 61850-9-2 process bus for a typical substation is given in Kanabar and

Sidhu (2011), by studying the time-critical sampled value messages delay and loss with OPNET simulations. Situational awareness in power system control centers is currently changing, with increased requirements forced by variability in generation and wider interconnected networks. Lessons learnt from severe blackouts all over the world are leading towards improvements in power system stability and security tools, as well as system analysis. One solution for both wide-area monitoring, protection and control, and the visualisation of such wide-area systems conditions is given by the use of PMUs.

Two primary ways of taking advantage of PMU data can be currently identified as follows:

- Improve situational awareness by directly displaying phasor information for operators in control centers (Hoffmann and Capitanescu *et al.*, 2011);
- Improve SCADA systems performances by streaming data from PMUs in a standard format and checking state estimator results automatically based on that data (Farantatos and Renke *et al.*, 2011).
- The advantages of PMUs are straightforward in these applications and are given by their precise time identification of measurements together with high sampling rates.

In traditional SCADA systems, data are scanned in a sequential manner and a session of data retrieval can take between 1 and 5 seconds. With this resolution, the supervisory system cannot observe power system oscillations, let alone control them. Moreover, this sequential scanning can lead to discrepancy cases, where different states of the power system are recorded within the same snapshot. For example, when a circuit breaker is tripped, the operator can see the “open” status of the breaker and non-zero power flows on the line it is connected to, or vice-versa. This situations can only be solved at the next system scan and can affect state estimation and more importantly, decision-making processes. PMUs, by their time-stamped data streams, can easily avoid such discrepancies.

PMU-based controls can use either client-server architectures or peer-to-peer communications between relays. PMU data streams can be easily converted to DNP3, Modbus or other standard protocols. Recently released, the IEEE C37.118 protocol provides high-speed and accuracy specifications for PMU data that can be used in SCADA updates, system integrity protection schemes (SIPs) arming or in messages for telecontrol over Ethernet, like GOOSE (specified by IEC 61850).

Within IEEE C37.118 specifications, a PMU message data field includes both analog and digital values (eg. frequency, rate of change of frequency, voltage and current phasors and others). In addition to PMU data, analog data can also be streamed by PMUs, in 16 bit integer format or 32 bit floating point values, based on calculations performed at the PMU level (apparent impedance of lines or loads, calculated beads on current and voltage magnitudes and angles measurements, power flow or direction of power flow on a line, or even the temperature of a line based only on voltage and current measurements).

PMUs can also be connected to programmable automation controllers to receive analog data via GOOSE messages or directly to external instrumentation devices using transducers and GOOSE messages. Analog inputs of interest in smart grid applications include oil level, pressure, temperature, shaft speed, transformer tap positions and others. This time-stamped data becomes valuable in smart grid operation, by providing accurate information about equipment located in substations.

An example application of analog values utilisation from PMUs is the monitoring of dynamic load limits in power networks based on temperature measurements (Jenkins and Dolezilek, 2011) and a real-world case study for controlling parallel transformers with on-load tap-changer (OLTC) by using IEC 61850 GOOSE messages between the regulators is presented in (Gajic and Aganovic *et al.*, 2010).

Another application of combined PMU data and analog data stream from PMUs is the synchronisation of generating units with the network. By streaming PMU data like angle, magnitude, frequency and rate of change of frequency to a static VAr compensator (SVC) and a visualization system, from a PMU located before or after a synchronization circuit breaker, the breaker can be manually closed or the governor of islanded generation can be adjusted (Koellner and Anderson *et al.*, 2005).

One important application of PMU streams in smart grids is the detection of islanded condition for distributed generation (DG). IEEE 1547 requires a maximum time of 2 seconds to detect an islanded condition with distributed generation. This time frame can be achieved by implementing a trip scheme for the DG unit based on fast detection of threshold violations of angle, slip and acceleration levels. The slip and acceleration can be calculated based on measurements from two PMUs, one placed next to the DG unit and one in the substation (Mills-Price and Scharf *et al.*, 2010). In all applications above, phasors and other data in the IEEE C37.118 standard format are used in order to implement new smart grid functionalities (Flerchinger and Moxley *et al.*, 2011).

Information transmission and security

At present cyber security management have a fragmented approach, with responsibility for cyber security split across different parts of the electricity networks companies. Therefore, an integrated approach is required with redefining interdepartmental boundaries and interfaces between National Grid and DNOs with regard to cyber security role and responsibilities.

Smart Grid requires transparent information flow between transmission, distribution, generation, home, and other communication networks such as the networks used for energy trading. There is broad agreement that the grid of the future will feature far more distributed generation resources than today's largely centralised system.

To incorporate intermittent energy resources, which includes some forms of renewable energy, electricity networks will have to become “smarter grids with integrated communication systems and real time balancing between supply, demand, and storage” (Crossley and Beviz, 2010). Smart Grids builds on many of the existing technologies used by utilities and many of the necessary internationally recognized standards in the field of power already exist. Smart Grids are characterised by a large number of players and disciplines, therefore inter-domain cooperation and coordination is necessary focus on interoperability.

Electric Vehicles and transport

The move towards a low carbon society will require progress in parallel areas: (i) renewable energy production to meet EU’s energy goals for 2020 which include the aim of having 20% of total energy supply from renewable sources and (ii) e-mobility. Both require smart grids to achieve their potential. Some energy sources, e.g. wind and solar power, are dependent on the weather, resulting in uneven energy generation patterns (DECC, 2011i). Electric Vehicles and other appliances that store energy can be used to compensate for peaks and valleys in the supply of and demand for electricity, and thus help to optimise grid management (Kempton and Udo *et al.*, 2008).

Plug-in EVs, which can be charged at home, offer great potential for demand response, especially in load shifting. Therefore, EVs should be integrated into the electricity supply through advanced smart grid networks with two-way communication technologies. This concept is called “Vehicle-to-Grid” (V2G) (Kempton and Udo *et al.*, 2008; Pillai and Bak-Jensen, 2011; Kempton and Tomic, 2005).

Smart Grid transformations place a greater emphasis on demand response and the potential role of electric vehicles (EVs) as a distributed energy storage resource to provide load shifting in a smart grid environment will be fully exploited. Smart Grids will be necessary to accommodate plug-in hybrid electric vehicles (PHEVs, two-way communication technologies for “vehicle-to-grid” (V2G), as well as distributed generation and storage capabilities (Ipakchi and Albuyeh, 2009; Coll-Mayor and Paget *et al.*, 2007).

The EV uptake is supported by the UK government through incentives for EV acquisition and use such as reduction in upfront costs and favourable tax regimes (DfT, 2008). In addition, OLEV allocated funds for eight pilot projects with regards to EV charging infrastructure installation and trials as reported in Plug-in Vehicle Infrastructure Strategy (DfT. Office for Low Emission Vehicles, 2011). An important document prepared in 2009 for the European Topic Centre on Air and Climate Change aggregated the findings of over 350 studies and estimated that the share of electric vehicles in 2030 will be anywhere from 5% to 50%, depending on whether pessimistic or optimistic assumptions are used (Hacker and Harthan *et al.*, 2009). The success rate of e-mobility is intrinsically linked to smart grid development as the charging infrastructure is a pre-condition for large-scale adoption of electric vehicles (ENA, 2010b).

The widespread use of EVs will require the development of standards to ensure harmonisation and interoperability between different manufacturers, technologies and country regulations, and provide simplicity to EV owners.

3. Scenarios themes (cross-cutting)

This section summarises themes that emerged in this literature review, that appear to cut across several disciplines and should therefore be included in the overall scenario development. These themes may be complemented by others, not covered in the literature review; to this aim the input of the Project Advisory Group would be extremely beneficial.

3.1 Security of Supply

Security of supply is a theme of strategic importance for all actors and is drawing increasing attention, partly due to the approaching end of life of a significant proportion of the UK's energy supply infrastructure. Although some of this generation will be replaced by renewable sources, security of supply weaknesses may persist due to the intermittent nature of some renewable sources, and need to be addressed.

The threat of supply disruption appears to resonate with some segments of the public (Spence *et al.*, 2010); therefore framing smart grid development around energy security may provide potential for acceptance of smart grids, at least within certain segments of society. However, acceptance of smart grid components is not generally expected to be a major issue, as most smart grid related changes will not be seen by the public.

Interestingly, despite its impact on the function of society and the economy, security of supply was not, until recently, within the remit of Ofgem. However, Ofgem is now responsible for securing long-term energy supply with regard to sustainable development (DECC, 2011c). Security of supply is also a goal to be addressed with the application of the Low Carbon Networks Fund (DECC 2011c; Ofgem, 2011c).

3.2 Cyber security, privacy, and control

Data security is a clear consumer concern (EPRI, 2011) both from a data governance aspect (i.e. who may be allowed to access what level of detail) and a cyber-security aspect (i.e. whether data usage could be accessed by intruders). Cyber security is also a sensitive point for operational aspects as well (Tritschler and Mackay, 2011), and this way it links to reliability of supply. The latter is now high on the agenda, especially after the 2003 and 2004 blackout events in the US and Europe.

One aspect of smart grids of relevance to security is that existing commercial cloud applications, which are one option of managing smart grids operations and data, are not addressing data security and privacy adequately (Cachin and Schunter, 2011).

Adjacent to fragmentation issues (section 3.3), current cyber security approaches appear to be equally fragmented and therefore offering varying levels of access opportunities across the country. Addressing this issue becomes even more urgent with the introduction of smart meters, as they could provide access to private data, and their security should thus be placed under consumer protection schemes. The latter have currently been weakened with the pending abolition of the short-lived Consumer Focus.

3.3 System fragmentation responsible for several problems

The existence of different DNOs operating as independent businesses means several different standards technologies and protocols for the distribution and supply of electricity. This leads to different business models and therefore funding models, none of which is sufficient to provide a viable business case, yet in combination with others provides the utility's required return (Jackson, 2011).

At the same time, this poses a barrier for the transition to a decentralised system, which is considered important for SGs; such decentralisation is prevented because DNOs, operating as independent businesses, favour tried and existing technologies in order to minimise risk and maximise returns. This creates lock-ins in different technologies at different levels of different DNOs, which consequently discourages change, innovation, and interoperability.

System fragmentation also presents increased cyber security risks due to different security standards, and hence poses a threat to energy security and network disruption.

3.4 Electric Vehicles and heat important to SGs

The potential for substantial uptake of electric vehicles and electrification of heating to act as a major driver for smarter grids has been noted in a number of sections of this review. This is due to (a) the potential storage capacity of electric vehicles, which allows the possibility of feeding some of the energy stored in the vehicle battery back to the grid to satisfy some of peak demand (UKERC, 2011); (b) the electric vehicles and electric heating burden on an electricity system already working to its capacity; therefore additional energy demand for battery charging and heating must be managed so as to prevent further increases in peak demand (UKERC, 2011).

Public attitudes to electric vehicles appear to be positive in principle (DfT and GfK, 2008). However, important perceived barriers persist, such as high investment cost (Screeton, 2013) and performance worries (EST, 2010c), mainly range anxiety.

3.5 Microgeneration and decentralisation are important smart grids components

Micro-generation is generally very important for low carbon electricity systems, e.g. to alleviate system congestion (Baker *et al.*, 2010). In the case of decentralised generation, micro-generation becomes critical and is partly supported by current policy via Feed-in Tariffs. Micro-generation, especially in a wider decentralised context, also offers maximum benefits in terms of demand reduction by fostering energy citizenship – individuals taking active control of their energy production and consumption, and consciously changing their behaviour to optimise both (Devine-Wright, 2007).

The existing multitude of DNOs and their risk averse culture are major barriers to decentralisation and micro-generation, as they discourage substantial investment on innovation. In addition, the UK still operates in an energy market environment which is based on central generation. Another important barrier is the high initial costs involved in micro-generation and decentralisation of electricity production.

Virtual power plants add another aspect to decentralised generation. Given adequate commercial and regulatory support, virtual power plants will emerge (Pudjianto, *et al.*, 2008), which will depend on the cooperation of those who are in control of the relevant energy resources (Wolsink, 2012).

3.6 Smart meters

Smart meters appear to be a genuinely cross cutting component of smart grids, although they are not universally perceived as necessary for a smart grid (ERGEG, 2010). They are also expected to deliver demand reduction from better information and use of energy and load shifting to off peak times (DECC, 2010); however specific estimates of these benefits fluctuate wildly with different calculations (Darby, 2006). In addition, any benefits will be limited where smart meters are implemented as standalone demand management measures (Burgess *et al.*, 2011), and results from early smart meters pilot projects have been mixed (Mah *et al.*, 2011). Smart meters could, however, provide clearer energy consumption information to consumers.

The costs associated with smart metering (development and implementation) will not be negligible, and will be borne ultimately by consumers, as supply companies will be allowed to pass on these costs to consumers. Therefore consumer reaction may significantly impact on the roll out of smart metering schemes.

There are persisting consumer concerns in respect of data use (e.g. in terms of energy companies misselling products, especially to the more vulnerable) and broader data security (see point 3.2).

3.7 Distrust

Distrust towards energy companies is widespread and for a multitude of reasons; most notably in terms of fears of raising tariffs once consumers switch to off peak tariffs (Defra and Brook Lyndhurst Ltd., 2007), not passing on any associated smart grids savings to the customer (Lineweber, 2011), abusing data from smart meters, in order, for instance to mis-sell their products and services to the customer, and general data protection concerns. Energy supply companies were asked to commit to refraining from such practices (Which?, 2012a) but were generally reticent to do so. The UK government finally announced in April 2012 that it would ban selling of energy products during the smart meter rollout (Which, 2012b). Distrust is worsened by the lack of appropriate and powerful customer support structures.

We expect that these themes will form the core of our scenario approach, and help explore the potential direction of the development of smarter grids in varying conditions.

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Appendix A: Smart Grid Pilot Projects

List of UK pilot projects (from Eurelectric)

Active Network Management

Organization: Smart Grid Solutions (UK)

Period: Apr 2010-Apr 2011

Project category: Grid Automation Distribution

Project Description: Delivering a fully automated, remotely configurable and self-healing power distribution Network that will allow grid wide demand / load management in real time.

Central Networks Low Carbon Hub - Optimising renewable energy resources in Lincolnshire

Organization: Central Networks (UK)

Period: Jan 2011-Dec 2014

Project category: Grid Automation Distribution

Project Website: www.eon-uk.com/distribution/lowcarbonhub.aspx

Project Description: The low Carbon Hub will demonstrate how substantial levels of renewable generation can be connected to a primary distribution network.

CET2001 Customer Led Network Revolution

Organization: CE Electric (UK)

Period: Jan 2011–Dec 2013

Project category: Smart Meter and AMI

Project Website: www.networkrevolution.co.uk

Project Description: This project will explore how new tariffs can alter customer behavior, enable networks to respond more flexibly to customers by using advanced voltage control devices, explore ways for networks and smart meters to communicate, monitor 600 intelligent white goods and 14,000 smart meters.

Clyde Gateway

Organization: Scottish Power (UK)

Period: Apr 2010–Apr 2011

Project category: Grid Automation Distribution

Project Description: To demonstrate the latest smart grid technology and use the learning to develop proposals for wider and larger scale smart grid applications across Glasgow and UK operations.

Cryogenic Storage

Organization: High view Power Storage (UK)

Period: Apr 2010–Apr 2011

Project category: Specific Storage Technology Demonstration

Project Description: The project is being run in two phases: Phase 1: the CryoGenset pilot demonstrator has been commissioned for six months and runs on a regular basis exporting electricity to the National Grid. Phase 2: the fully integrated CryoEnergy System.

Data Exchange

Organization: National Grid (UK)

Period: Apr 2010–Apr 2011

Project category: Grid Automation Transmission

Project Description: The Data Exchange was established to identify an enduring solution to the interaction between the STC and Grid Code regarding the exchange of User data.

Low Carbon London - A Learning

Organization: UK Power Networks (formerly EDF Energy)

Period: Jan 2011–Jun 2014

Project category: Smart Meter and AMI

Project Description: This project will implement new tariffs for EV's, set up a learning laboratory at Imperial College London to test how large-scale low carbon technologies impact on networks, Install and monitor 5,000 smart meters and monitor EV charging patterns. An integrated, large-scale trial of the end-to-end electricity supply chain. Cumulative CO_2 savings of 0.6 billion tons between 2011 and 2050. In financial terms, the carbon benefits from a national rollout would give an NPV of £29 billion to 2050. £12 billion NPV of financial benefits for customers up to 2050.

LV Network Templates for a Low-carbon Future

Organization: Western Power Distribution (UK)

Period: Jan 2011–Dec 2013

Project category: Smart Meter and AMI

Project Description: Assist in the design and planning of national networks in the future, in order to accommodate large-scale renewable generation and changes in customer utilization.

Plugged in Places

Organization: Various (UK)

Period: Apr 2010–Apr 2013

Project category: Home application – Customer Behavior

Project Description: The Plugged-in Places will provide the charge points to support 'Plug-in Cars' – pure electric vehicle (EVs), plug-in hybrid electric vehicles (PHEVs) and hydrogen cars. They are intended to demonstrate how electric vehicle charging works in practice in a range of different settings – urban, suburban and regional – as well as testing innovative technologies such as rapid charging, inductive charging and battery swap.

Smart Grid Demonstration System

Organization: Arqiva (UK)

Period: Apr 2010–Apr 2011

Project category: Integrated System

Project Description: Arqiva will use its dedicated UHF spectrum, combined with Sensus' purpose designed security measures, to provide a bespoke communications network for independent use by the UK's water, gas and electric utilities.

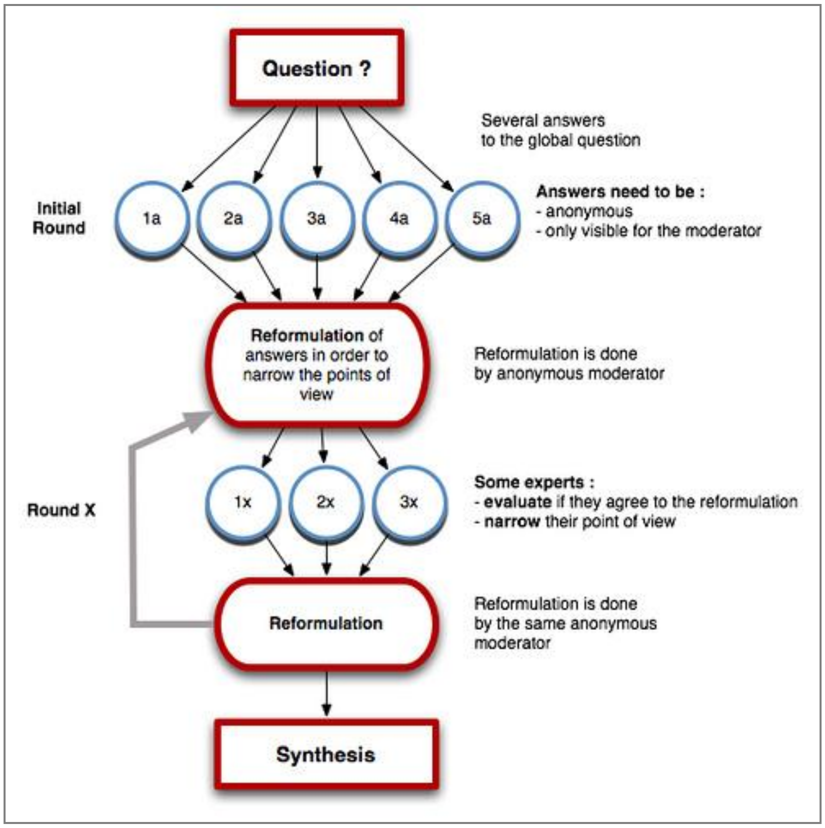
Appendix B: Delphi studies

Several projects have used Delphi (or variants, such as Policy Delphi and expert elicitation) methods to elicit stakeholder and/or expert views on energy system futures. Certainly not all energy scenarios are developed through Delphi-type techniques (e.g., McDowall & Eames, 2006) but the advantages of Delphi include its 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 (Gordon, 1994) and/or where long-range predictions are required (Stevenson, 2010). Delphi methods are often combined with other methods (ibid), including workshops, multi-criteria decision-making and scenario development (Stevenson, 2010; Georghiou, 1996).

The Delphi approach uses an iterative method in which there are several (most 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, thus contrasting with both academic dissemination and data collection via expert interviews or focus groups. An additional advantage of anonymous reporting is that participants are not tempted to follow the opinion of established figures in their area. At a next step, participants reach a group judgement on the basis of aggregated, anonymised feedback (rather than attributable opinions and group influence; Rowe & Wright, 2001).

Delphi studies may include (a) questions about participant background (e.g., expertise); (b) broad questions about the sector and drivers of the technology/change; (c) more specific questions about technical issues, societal trends, international context, etc.; (d) barriers and wildcards (e.g., disruptor technologies); and (e) options and strategies to advance change/development of the technology or issue in question (Stevenson, 2010). Questions are often formulated as statements about the state/performance/penetration of a particular technology, e.g., '50% of vehicles in European Union produce zero emission (other than CO_2 and water; Georghiou, 1996). Alternatively, questions may be broader and potentially open-ended; e.g., 'List four trends or issues and their driving causes that you believe may influence the sector up to 2015'; 'Identify technologies, breakthroughs, scientific advances or innovations needed to underpin products, processes or service'. Responses may focus on impacts, timing of occurrence, feasibility, etc. (Stevenson, 2010; REACT, 2011).

Appendix Figure B.1: A sample Delphi procedure



Source: http://trendsoutheast.org/2011/all-issues/issue-02/delphi-method/

Policy Delphi (Turoff, 1970) – a variant of classic Delphi methodology – differs from conventional Delphi in that it does not require participants to reach a consensus, instead identifying and understanding divergence in opinions. When properly conducted, Policy Delphi can be a very demanding exercise, for researchers and participants alike; but also provide rich data. It is more suitable than conventional a Delphi method where participants are heterogeneous and/or the topic involves advocating a particular policy (i.e., not simply a technical assessment). Policy Delphi aims to produce several policy options as outputs from the process (rather than a single, consensus view); this is another advantage of this approach for our study in which we aim to develop several distinct scenarios. Thus, Policy Delphi allows all options to be considered, and to measure their consequences and acceptability (Linstone & Turoff, 2002). Stages involved in Policy Delphi include: formulating the issues, exposing the options, determining initial positions on the issues, exploring reasons for disagreements, evaluating underlying reasons, and re-evaluating the options (ibid). Options are rated according to their desirability, feasibility, importance and/or risk/confidence (using Likert scales with no midpoint/undecided options).

As with any research method, Delphi and similar methods have limitations, including unavoidable biases/heuristics (discounting, anchoring, etc.) in judgement and perception (e.g., Kahneman *et al*., 1982) and other, avoidable biases associated with sampling, question wording and questionnaire design. Delphi studies may also fail due to poor summaries of group responses in subsequent rounds, imposing the researchers' view of the problem and (policy) options, underestimating the demanding nature of the process for participants (Linstone & Turoff, 2002) and lack of theory (Stevenson, 2010). These issues call for researcher attention to the design, implementation, and analysis phases, as well as the need for cross validation of findings among experienced researchers in order to minimise errors in interpretation and reporting.

Given the breadth of our project and dearth of necessary available data, and in combination with the diverse audience we need to approach, Delphi type methodologies are well placed to address our research questions, and our team has considerable previous experience in this line of research. Several comparable Delphi-type studies are outlined here (section 1) along with suggestions for how we might use/adapt these methods for our project (section 2):

1. Previous Delphi and related studies

- EurEnDel (Energy)

EurEnDel (2004) was the first Europe-wide Delphi study on future developments (to 2030) in the energy sector, funded under the 5th Framework Programme of the EC. Participants were experts in energy. Over 3,400 energy experts from 48 countries were invited to participate in the two-round, web-based Delphi exercise; response rate in the first round was around 20%. The survey examined expected and ideal futures: i.e., 'What will the future be like?'; 'What should the future be like?' The results led to development of three scenarios of European energy futures to 2030.

Questions asked in the Delphi included:

(a) *Timing of occurrence*: participants were asked when different technologies would achieve certain levels of market penetration (e.g., for Energy Demand: 'Industrial energy consumption in Europe is reduced by 50% per produced unit through novel production processes'; for Transport, 'Fuel cell driven cars reach a European market share of 20%'). Certain 'wildcard' technologies (e.g., cold fusion) were also included.

(b) Actions needed: participants were asked what actions were needed to reach the particular level of technology adoption, including: Increase in Basic R&D; Increase in Applied R&D; Fiscal Measures; Regulation; and Public Acceptance.

(c) *Impact assessment:* participants were then asked to rate the impacts of the technologies identified on Wealth Creation, Environment, Quality of Life and Security of Supply.

(d) *Importance of technologies for societal 'visions':* participants then rated the importance of the energy technologies/sources for three different value-based societal visions (Individual Choice; Ecological Balance; Social Equity).

Results: in respect of electricity grids, the project found a large consensus that decentralised supply would prevail: 30% share of decentralised generation is expected by 2020. In contrast there was more disagreement over when (if at all) large international grids enabling regional renewable energy supply (e.g., solar thermal exported from N. Africa) would occur. Renewables, followed by energy efficiency, were most highly rated across the assessment criteria. Demand management techniques/technologies were most highly rated in importance across the three visions. Little cross-national variation in views was observed (except in respect of nuclear technologies); while some variation by level of expertise was noted (experts rated nuclear fission more highly than energy conservation for security of supply).

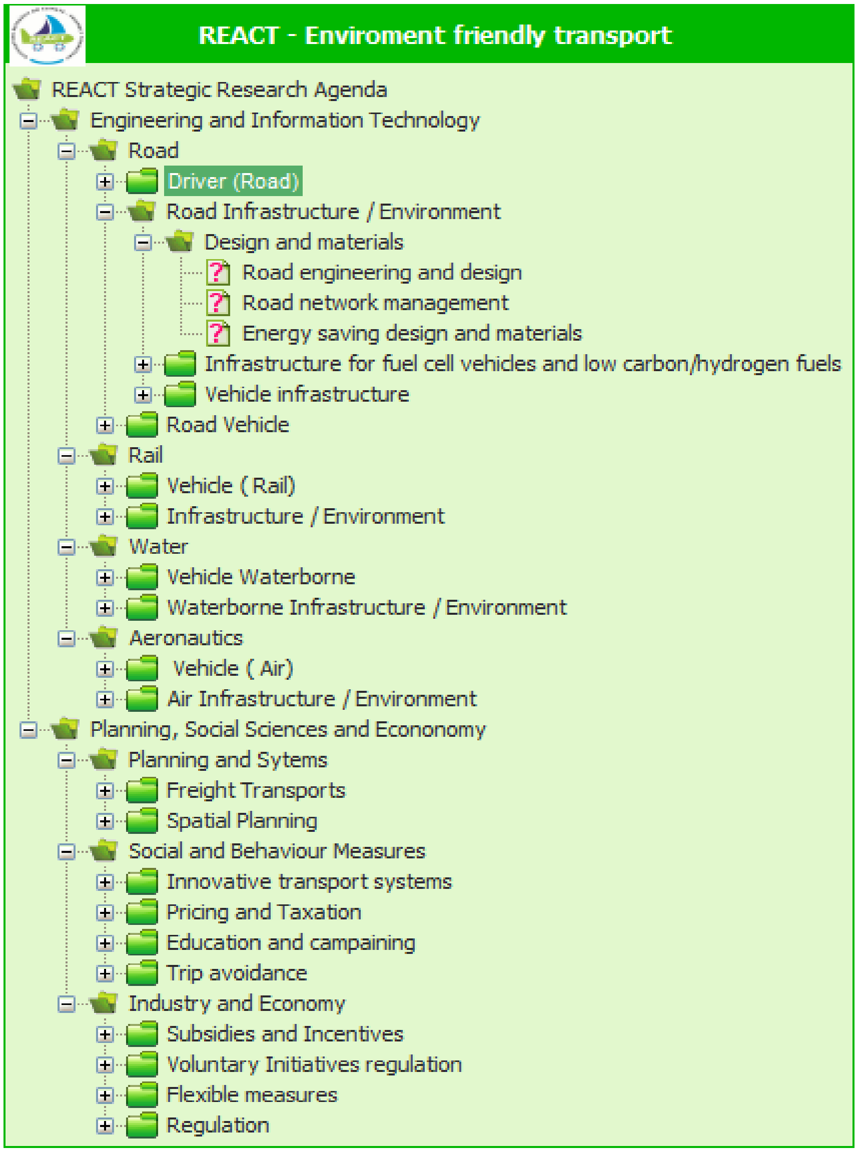
- MATISSE (Sustainability) (see www.matisse-project.net)

The FP6 EC project MATISSE (2008) comprised several case studies, including sustainable transport, and involved eliciting views of experts, stakeholders and public on visions and pathways to a sustainable future in Europe. The transport case study involved visioning workshops and questionnaires to both (non-expert) public and (expert) stakeholders. As with EurEnDel, questions addressed both ideal and expected futures, as well as barriers to achieving both.

- REACT (Transport) (see www.react-transport.eu)

This FP7 EC project focussed on the prioritisation needs for R&D for low-carbon transport in Europe. It included a Delphi study to elicit expert and stakeholder views on the timescale and impact of research and implementation in all aspects of low-carbon transport R&D. This online Delphi included views of approx. 50 expert participants from academia, European policy making authorities and relevant industries. Participants were asked to select from a broad array of carbon emission reduction measures and technologies and evaluate them on a number of relevant dimensions.

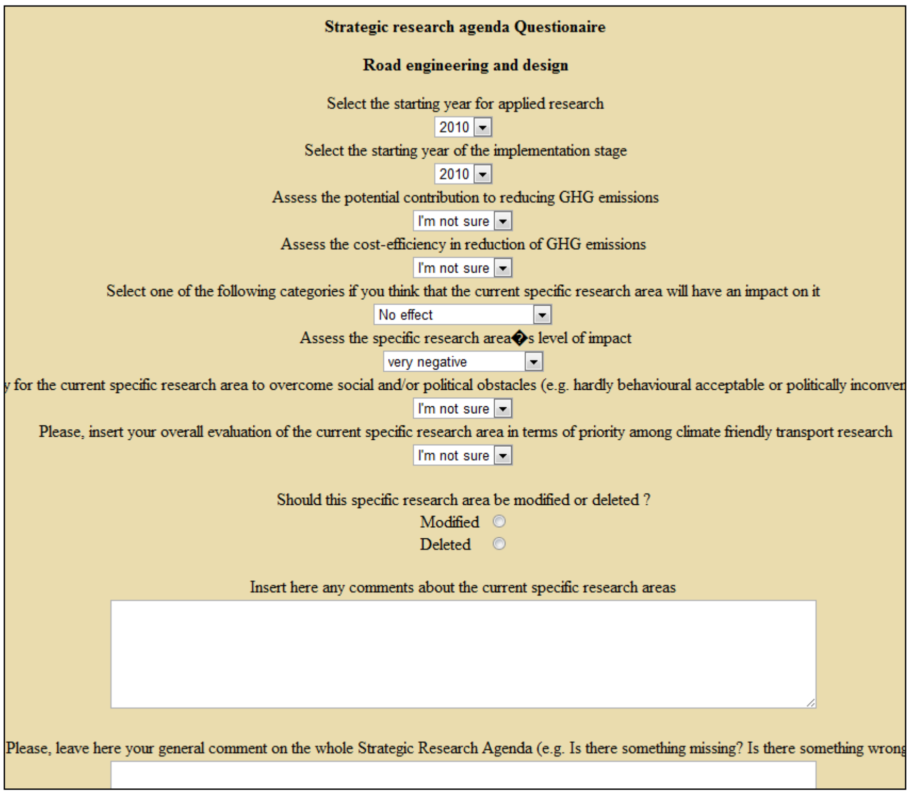
Appendix Figure B.2: List of carbon emission reduction measures and technologies



Source: REACT

These included, for each selected category of measures, the starting year for research and implementation, the potential impact to reducing GHG emissions, the cost efficiency of the measure, potential social and political obstacles, overall importance rating, as well as whether this area should be modified or deleted. Participants were also allowed to leave general comments for further evaluation.

Appendix Figure B.3: List of evaluation criteria for each carbon emission reduction measure and technology.



Strategic research agenda Questionaire

Road engineering and design

Select the starting year for applied research

2010

Select the starting year of the implementation stage

2010

Assess the potential contribution to reducing GHG emissions

I'm not sure

Assess the cost-efficiency in reduction of GHG emissions

I'm not sure

Select one of the following categories if you think that the current specific research area will have an impact on it

No effect

Assess the specific research area�s level of impact

very negative

y for the current specific research area to overcome social and/or political obstacles (e.g. hardly behavioural acceptable or politically inconver

I'm not sure

Please, insert your overall evaluation of the current specific research area in terms of priority among climate friendly transport research

I'm not sure

Should this specific research area be modified or deleted ?

Modified

Deleted

Insert here any comments about the current specific research areas

Please, leave here your general comment on the whole Strategic Research Agenda (e.g. Is there something missing? Is there something wrong

Source: REACT

- Supergen HDelivery (Stevenson, 2011)

First round involved 52 participants from several countries, spanning policy, industry, lobbying and research. Questions included predictions about 'worldwide hydrogen production used as an energy vector for 2020 to 2050', 'key drivers for the development of a hydrogen economy', 'key barriers slowing or preventing the development of a hydrogen economy', 'key developments in the hydrogen economy which you anticipate in the next 40 years'; benefits, impacts, potential, barriers, etc. of various hydrogen technologies; production priorities; risks and public perceptions; and key sustainability issues (GHG reduction, use of renewables, pollution reduction, H_2 cost, fossil fuel cost, living standards, and energy poverty).

- UK Technology foresight programme (Georghiou, 1996)

This was a major project which drew on extensive experiences from Japanese Delhi exercises, in which 8,384 questionnaires were sent out to wide-ranging expert groups (achieving a 31% response rate; 41% of whom participated in the second round). As with most Delphi studies, participants were predominantly over 50 and male; industry was also well-represented. The adapted the 'Trends, markets and technologies questionnaire' which covers a logical chain of questions: 'List four trends or issues and their driving causes, that you believe may influence the sector up to 2015'; 'Identify possible new market opportunities arising from trends or issues and driving causes'; 'identify possible new products, processes and/or services to meet the needs of some of the market opportunities'; 'and 'Identify technologies, breakthroughs, scientific advances or innovations needed to underpin products, processes or services'.

This initial scoping stage led to identification of 80 topics per subject panel (e.g., agriculture, natural resources and environment) which were addressed by sub-groups of experts in the next round. Here, Delphi statements were used to elicit responses pertaining to expected time of occurrence of technological development according to four levels (elucidation, development, practical use, and widespread use). In addition, degree of impacts (wealth creation, quality of life, etc), UK's current position vs. other countries, need for collaboration, constraints on occurrence, and other issues/comments were recorded.

- Tyndall Carbon Capture & Storage (Gough, 2008)

Questionnaires were sent to 242 professionals, of which 88 were returned completed. Despite using convenience samples, participants represented a spread of expertise. The questionnaire commenced with 'landscape' questions address the context of CCS technology; 'What are the key drivers for energy technology deployment in the UK?' (CO2 emissions, energy security and costs, being the top three responses).

Next, barriers were addressed ('What are the three most important challenges that, in your opinion, could prevent the implementation of CCS in the UK?') followed by expectation and preference for the electricity supply fuel mix to 2040 ('what do you expect [would you like] the fuel mix to be?'). Responsibility for paying for pipelines, timescales for use of different storage options, ease of monitoring and repair, cost attribution, options for cost reduction, and risks ('What are the key technical uncertainties associated with storage of CO_2?' '– In your opinion, how does this risk compare to the environmental risk associated with an equivalent (in terms of CO_2 reductions) use of nuclear power?'), capabilities, and support for different policy options, were also addressed.

2. Suggested methods and questions for our project

The aim of our Delphi study (Task 1.3) is to establish scenario dimensions and examine stakeholders' assessment of their relative importance. Dimensions identified here are to be used in WP2 to define scenarios. The anticipated method involves an anonymous iterative process to elicit opinions in an uninhibited fashion, subsequently presenting these back to participants for further comment, and highlighting points of disagreement without necessarily seeking consensus. Drawing on tasks 1.1 and 1.2, there will be two rounds of consultation:

- <u>Round 1:</u> identify critical steps likely to determine the future shape of SGs (dynamically [2020–2050] and spatially) and any factors upon which they are contingent. Also elicit key dimensions to distinguish scenarios (e.g., governance) and assessment criteria (environmental, economic, technical, social).
- <u>Round 2:</u> weighting the dimensions and criteria identified in round 1 using Multi-Criteria Decision Making Analysis (MCDM) (e.g., AHP) to identify priority

dimensions/criteria, and how weightings vary amongst different stakeholder groups.

Participants will include representatives from arrange of expert and stakeholder groups (network operators, suppliers, generators, regulators, policy-makers, interest groups, communities with experience of SGs and related technologies).

We aim to achieve a (final) sample of 50-100. Based on previous Delphi studies (Stevenson, 2010), this suggests an initial sample of 250-300 is required.

Questions:

(a) Background/demographics – including self-assessed expertise. Participants' self-assessed expertise in relevant topics will be measured (e.g., 'Expert', 'Knowledgeable', Familiar', 'Unfamiliar'; EurEnDel, 2004; see also Stevenson, 2010). Participants will be given the option to skip questions which they feel are outside their area of competence (cf. Stevenson, 2010; REACT, 2011).

(b) Establish priority concerns/needs to be addressed in respect of energy systems (e.g., fuel poverty / affordability, climate change, energy security, global competition, etc.)

(c) Expected and preferred futures (or preferred and barriers): e.g., Decentralised vs international supply… Note we need to consider whether SGs are indeed desirable! (not assume it)

(d) Benefits and risks of SGs?

(e) Critical steps for SGs (e.g., ‘to what extent is xxx required for SG roll out’ – could include penetration rates of EVs, heat pumps, smart meters, etc.)

(f) Branching/transition points? (e.g. consumer resistance to vs. acceptance of automated load control, branching to either high or low peak load shifting) – this will help provide the dimensions along which to differentiate scenarios. [Note: One option is that areas of controversy (i.e., divergence of opinion) are used to differentiate scenarios]

(g) Other?

Process and timeline:

1) Participants finalised and invitation letter sent (Feb 2012). As recommended by Linstone & Turoff, 2002), we will stress that invitees are participating in an exercise involving a peer group (i.e., mention backgrounds of others invited) and having genuine impact.
2) First round questionnaire finalised and piloted (Feb 2012) and sent to participants (Mar 2012).
3) First round data analysis (April–May 2012).
4) Second round questionnaire piloted (May 2012) and sent to participants (June 2012).
5) Second round data analysis (July–August 2012).

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