HubNet Position Paper Series

Smart Metering for the UK

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About HubNet

Hubnet is a consortium of researchers from eight universities (Imperial College and the universities of Bristol, Cardiff, Imperial College London, Manchester, Nottingham, Southampton, Strathclyde and Warwick) tasked with coordinating research in energy networks in the UK. HubNet is funded by the Energy Programme of Research Councils UK under grant number EP/I013636/1.

This hub will provide research leadership in the field through the publication of in-depth position papers written by leaders in the field and the organisation of workshops and other mechanisms for the exchange of ideas between researchers and between researchers, industry and the public sector.

Hubnet also aims to spur the development of innovative solutions by sponsoring speculative research. The activities of the members of the hub will focus on five areas that have been identified as key to the development of future energy networks:

- Design of smart grids, in particular the application of communication technologies to the operation of electricity networks and the harnessing of the demand-side for the control and optimisation of the power system.
- Development of a mega-grid that would link the UK's energy network to renewable energy sources off shore, across Europe and beyond.
- Research on how new materials (such as nano-composites, ceramic composites and graphene-based materials) can be used to design power equipment that are more efficient and more compact.
- Progress the use power electronics in electricity systems though fundamental work on semiconductor materials and power converter design.
- Development of new techniques to study the interaction between multiple energy vectors and optimally coordinate the planning and operation of energy networks under uncertainty.
- Management of transition assets: while a significant amount of new network equipment will need to be installed in the coming decades, this new construction is dwarfed by the existing asset base.

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Smart Metering for the UK

This position paper follows a colloquium held at Cardiff University on 8th February 2012 as part of the HubNet programme. The colloquium was organised by Brian Drysdale as described in Appendix I.

1 Introduction

The UK intends to install 53 million smart electricity and gas meters by the end of 2019 at a cost of £11.7 billion. The Department of Energy and Climate Change (DECC) anticipate that benefits to the approximate value of £18.7 billion will be realised by 2030 as a result of the smart meter roll out (implying a net benefit of £7 billion)[1]. The majority of benefits (approximately 82%) have been attributed to energy Suppliers (e.g. avoided site visits, improved customer supplier change) and consumer energy savings. DECC will oversee the UK roll out and aims to complete the project by 2020.

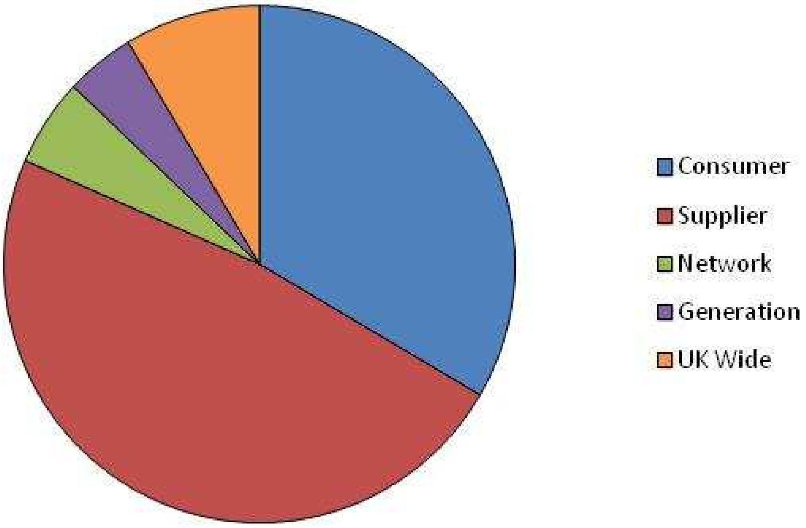


Figure 1 - Stakeholders benefitting from smart meter rollout. Taken from DECC impact assessment [1]

The UK Government's objectives and aspirations are indicated below[2]:

Consumers:

- Help consumers to better manage and reduce energy use
- Help consumers to save money
- Allow smoother and faster switching between Suppliers
- Provide more accurate bills

Suppliers:

- Create a wider range of services and tariffs
- Better manage customer relationships

Networks:

- Improve network efficiency and responsiveness
- Enable development of the smart grid

Policy:
- Aid transition to a low carbon economy
- Help deliver affordable, secure and sustainable energy supplies

A specification for smart meters is expected to be completed and published in the second quarter of 2012. This will be known as SMETS-1 (Smart Meter Equipment Technical Specification). A review period will follow publication and some meters may be installed. A second SMETS specification (SMETS-2) will be published, leading to the official roll-out of smart meters starting in the fourth quarter of 2014 (see Figure 2)

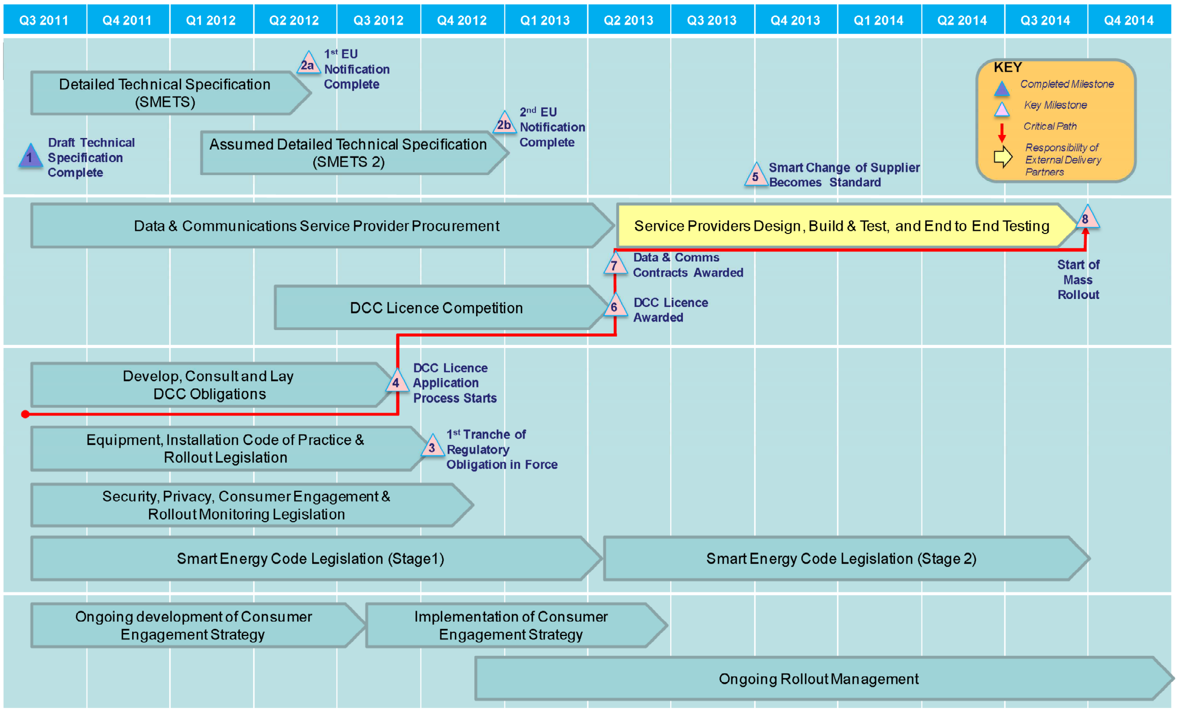


Figure 2 - UK smart metering specification and roll-out programme [3]

A smart meter is defined by OFGEM as[4]:

"...a gas or electricity meter that is capable of two way communication. It measures energy consumption in the same way as a traditional meter, but has a communication capability that allows data to be read remotely and displayed on a device within the home, or transmitted securely externally. The meter can also receive information remotely, e.g. to update tariff information or switch from credit to prepayment mode."

Functions such as voltage monitoring and outage detection are not included in the above definition. The definition requires expansion if electricity Network Operators are to gain significant benefit from smart meter installation. Numerous groups are advising the government on the specification for the UK smart metering system. These groups advise on topics including data security, customer engagement and overall system design (see Figure 3). The groups are made up of representatives from: industry, academia, NGOs (Non Governmental Organisations) and trade organisations.

The UK smart metering system implementation will be led by Suppliers. Consumer bodies report that trust in energy Suppliers is at an all time low; this could affect consumer acceptance and engagement with smart meters. Furthermore, there is no requirement, at present, for co-ordination between Suppliers or for standardisation beyond broad functional specifications. However, the DECC functional requirements [5] state that both HAN and WAN communication interfaces are "...*based on open and non-proprietary standards*", they also contain requirements for certification of interoperability.

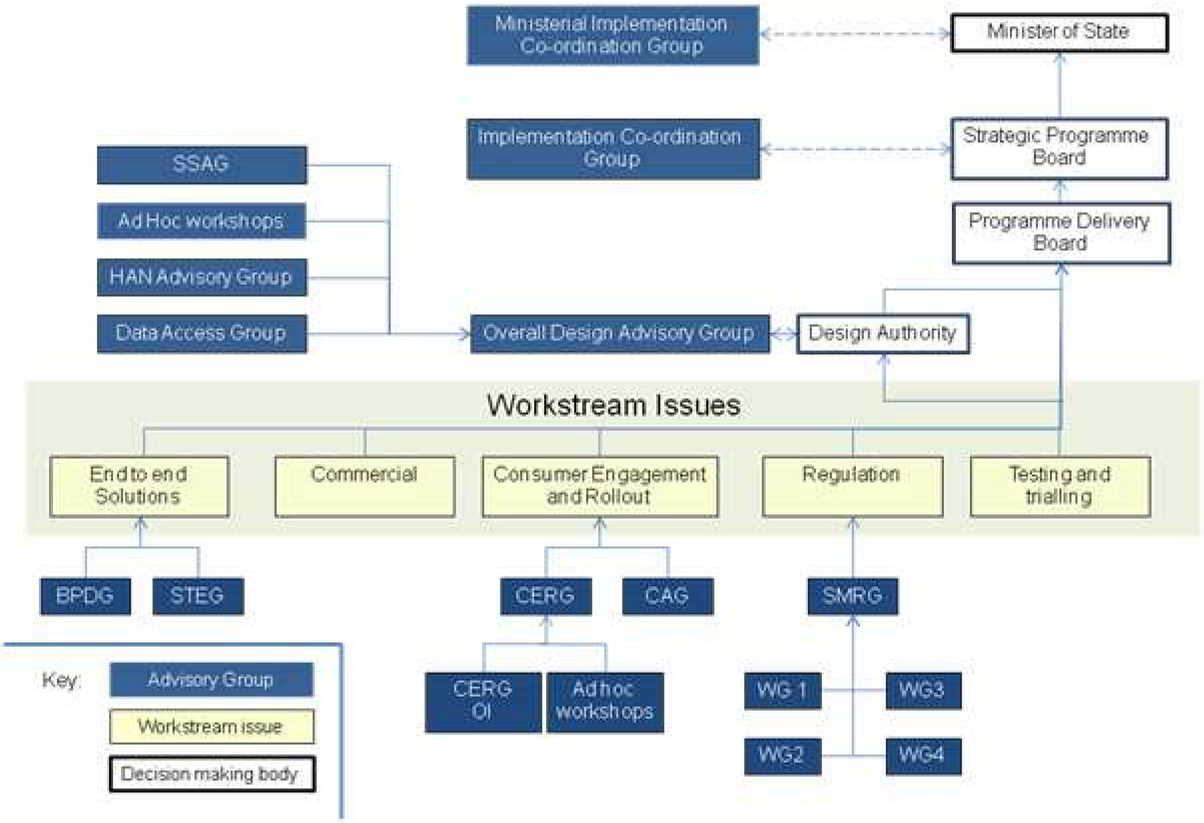


Figure 3 - UK Smart Metering System Design - working groups and responsible parties (BPDG - Business Process Design Group, STEG – Security Technical Expert Group, CERG – Consumer Engagement and Rollout Group, CAG – Consumer Advisory Group, SMRG – Smart Meter Regulation Group, SSAG - SMETS Advisory Group)[6]

Whilst benefits arising from the proposed UK smart meter roll out have been attributed to stakeholders, costs have not. There is a risk that consumers will not see the benefits attributed to networks, Suppliers and generation due to market inefficiency. The energy supply market has been accused of being uncompetitive[7] and there is considered to be scope for tacit collusion between Suppliers[8]. Lack of transparency in the market may result in the benefits from smart metering not being passed on to customers.

The UK proposals for import and export energy measurement could cause conflict between Supplier companies and Meter Asset Providers (MAPs). In the present system a customer, with a single Meter Point Administration Number (MPAN) can deal with separate companies for energy they import and energy they export. A scenario where two, or more, companies must store tariff information within the same meter is imaginable. It is possible that suppliers will not be in favour of commercial information being stored on devices that are available to competitors.

There is concern that the UK's balancing services code, the guidelines that determine the amount of backup generation available on the system, do not allow for energy use reduction from the demand side to be effectively taken into account. Therefore, it is possible that, with the present regulations, the availability of demand response will not result in a reduction in idling generation plant. However, a consultation on Electricity Market Reform is ongoing and may address these concerns.

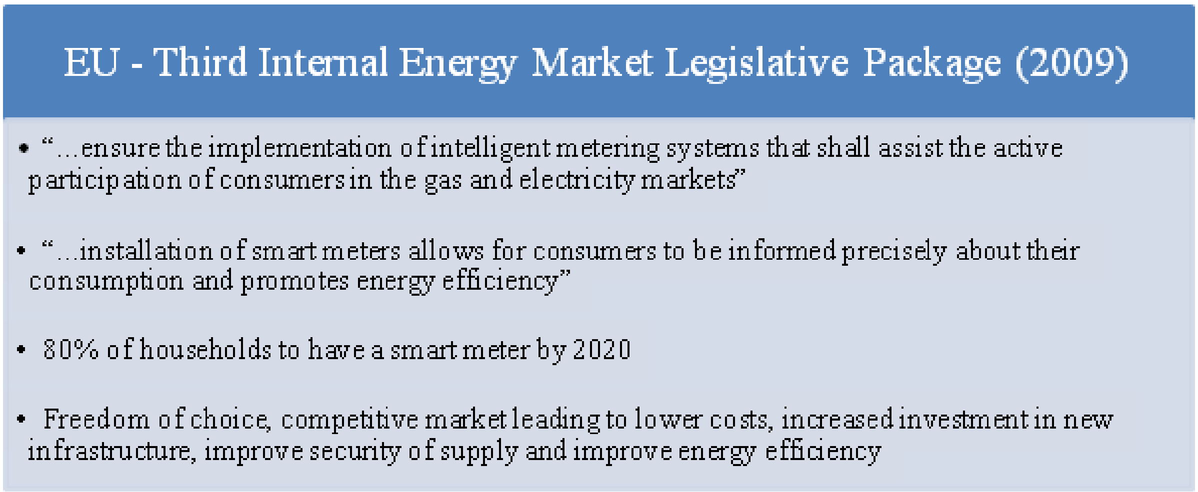
There are fears that the benefits realised by the smart metering system will not justify the costs. This is supported by a history of similar public projects with perceived large overspends or lesser than expected benefits, such as the NHS computer system in England[9]. Furthermore, in some other publicly funded projects, attempts at saving costs, following a large initial spend have resulted in redundant equipment or systems. In addition, MPs have expressed concerns that the forecasted consumer benefits, resulting from energy use reduction, may not be seen.

2 Justification of smart metering

Reasons for implementing smart metering systems can be divided into five categories: environmental, technical, economic, operational efficiency and behaviour change:

Environmental:	• Allow creation of low carbon energy system
Technical:	• Facilitate increased demand side participation to maintain balanced electrical system and improve asset utilisation
Economic:	• Increase competition and reduce costs
Operational efficiency:	• Improve system operation e.g. remote meter reading, earlier fault identification and rectification
Behaviour change:	• Encourage energy efficiency through enhanced feedback

Each of these aspects is influenced by legislation on: climate change (see Figure 4), competition in energy markets and security of supply. For example, the EU Third Internal Market Energy Legislative Package calls for more freedom of choice for consumers, improved security of supply and improved energy efficiency.



EU - Third Internal Energy Market Legislative Package (2009)

- "…ensure the implementation of intelligent metering systems that shall assist the active participation of consumers in the gas and electricity markets"
- "…installation of smart meters allows for consumers to be informed precisely about their consumption and promotes energy efficiency"
- 80% of households to have a smart meter by 2020
- Freedom of choice, competitive market leading to lower costs, increased investment in new infrastructure, improve security of supply and improve energy efficiency

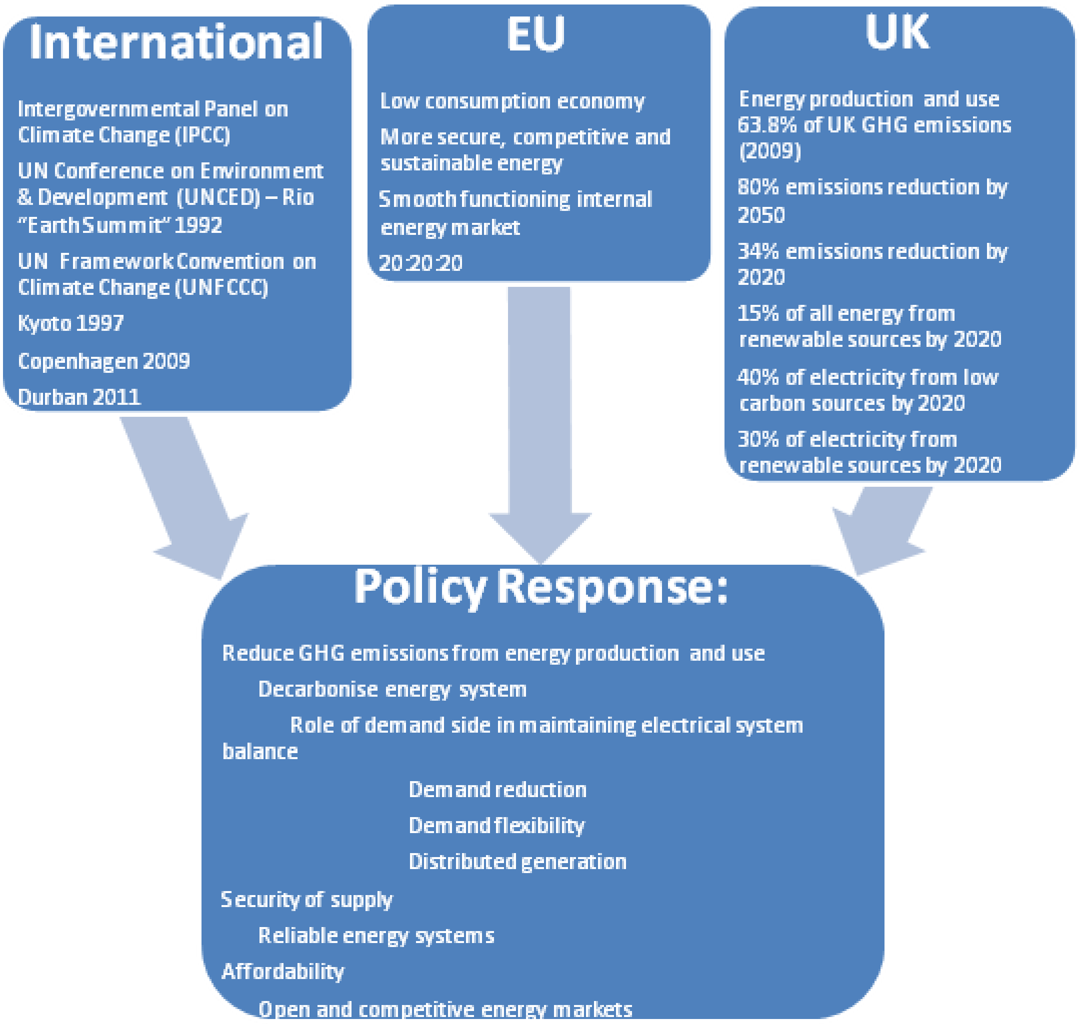


Figure 4 – Climate change directives and UK energy policy responses as justification for smart metering system (GHG = Green House Gas)[6]

3 The Consumer's Perspective

The UK consumer stands to benefit from reduced inaccuracy in billing, improved engagement with energy use and a downward pressure on costs, if the system is well implemented. However there are concerns that the returns arising from benefits attributed to networks, generators and suppliers will not be passed on to customers. Lack of transparency as costs are incurred may mean that consumers will not get value for money.

Approximately a quarter of the proposed smart metering system's benefits have been attributed to a reduction in domestic energy use. Consumer organisations warn that more than 5.5 million people in the UK are living in fuel poverty and are already rationing energy use. In addition it is possible that wealthy households may not be pre-disposed to taking steps to reduce energy loss.

The Energy Demand Research Project (EDRP) found that, where consumers were given smart meters with generic advice and graphical consumption comparisons, energy use was reduced by 2.3% in the first year and

4% in the second year. The EDRP Final Analysis report [10] suggests that smart meters alone will not have significant impact on demand. Further interventions may improve impact, these include: fitting of real-time display with clear feedback, advice on how to reduce energy use and tailoring of advice to particular customers.

Some commentators suggest that little meaningful response can be gained from demand side. However, in the Irish Commission for Energy Regulation (CER) smart metering trials[11], the deployment of a range of ToU (Time of Use) tariffs in conjunction with demand response stimuli were found on average to reduce overall electricity usage by 2.5% and peak usage by 8.8%. The EDF trials of ToU tariffs, reported under the EDRP, showed a reduction in peak usage of up to 10%, with increased impact on weekends and for households with one or two inhabitants.

> *"Consumers will benefit from smart meters only if they understand the opportunity to reduce their energy bills and change their behaviour. So far the evidence on whether they will do so has been inconclusive. Otherwise, the only people who will benefit are the energy suppliers."*
>
> **Margaret Hodge MP, Chair of the Committee of Public Accounts**

Smart meter installation programs in countries other than the UK have been impeded or halted by a lack of public acceptance. Public concern is based around data privacy/security concerns and perceived health risks from communication technology. Also, the UK government has stated recently that smart meters will not be mandatory. Therefore, if the public cannot be persuaded that having a smart meter is worthwhile, it is possible that it will become popular to refuse installation of smart meters. Opinion polls suggest that, at time of writing, approximately 50% of households would like a smart meter, approximately 25% do not want a smart meter and the remainder are undecided.

There have been suggestions that complex tariffs and long term contracts could become common after the smart meter roll-out. This situation is contrary to one of the proposed benefits, that customers will be able to more easily change supplier.

A focus of consumer organisations has been on the threat of salesmanship during smart meter installation. If smart meter installers are given incentives to sell anything to the customer, or to encourage them to sign away privacy rights, then an opportunity to engage with the customer and disseminate information about benefits may be lost.

4 Smart Metering System Communication

A Data Communications Company (DCC) will provide centralised management of smart meter data and communication systems. The initial scope of the DCC will cover secure communication, access control and scheduled data retrieval. A new code and licence will be created to define the operation of the DCC and a competitive application process will take place to select the operator. It is anticipated that the DCC license will be awarded in the second quarter of 2013.

A Wide Area Network (WAN) communication system will link the smart meters to the DCC. Since communication technologies will vary with location and may change over time, the WAN interface within each smart meter will be a removable module. The DCC will be responsible for the procurement and contract management of the smart meter data and communications services. The technologies used for the WAN will depend on the outcome of a competitive tender process. Appointment of the WAN service providers is planned for the second quarter of 2013.

No clear consensus has been reached on the technology that will be used for the WAN (Wide Area Network) communication system associated with UK smart meters. The four main options are cellular, broadband, powerline communication (PLC) and mesh radio, these are discussed in Table 1.

Technology	**Example protocols:**	**Narrative**
Cellular	GSM/GPRS, UMTS, EDGE	Well established and understood in the UK. Some areas do not have coverage.
Broadband	ADSL, Ethernet	Use broadband link as a bit-pipe, securely tunnel the data over public/private network (e.g. using IP based communications) Some areas do not have coverage.
Power Line Communication (PLC)	S-FSK	An emerging technique. May not be available during a power outage
Mesh Radio	RPL	Self-organising deployment, low cost, low power devices (802.11 / 802.15.4), Dense population required, this could cause problems with roll-out as Supplier led, so requires much co-operation between competing Suppliers.

Table 1- Candidate technologies for smart metering system WAN (Wide Area Network) communication systems

The communication latency, and thus the minimum reaction time to events detected by smart meters, depends on the communication method used. Three techniques for communication with smart meters, PLC, mesh radio and point to point (cellular), were implemented in the Irish Smart Metering trials[12]. The experience is summarised in Table 2.

It is probable that GSM/GPRS (Global System for Mobile communication/General Packet Radio Service) will be used in the near term. However, as UK smart meters are to include provision for an upgradable communication module, it is likely that no single technology will cover the entire system.

There are challenges in applying the wireless mesh radio solution to the smart metering system. The relatively large scale of the required network poses new problems. Networks must allow automatic discovery of connectivity and ensure multi-hop communication across nodes is possible. Furthermore, the system would need to adapt as topology changes, as links degrade or fail and as new nodes are introduced.

The IETF RPL (Routing Protocol for Low Power Lossy Networks) is inadequate for smart metering mesh networks as it does not allow automatic reconfiguration. However, the protocol is potentially useful if it is extended to include automatic detection of and connection to local concentrators (see Figure 5).

Technique	Selected Findings	Typical Latency	On Demand meter read, first attempt success rate
PLC [S-FSK] (Spread/Spaced Frequency Shift Key)	Improved performance was observed in newer area of the networks. Possible factors for this include number of cable joints, high impedance and common mode interference. It was noted that developing PLC standards such as ODFM (Orthogonal Division Frequency Multiplexing) may give improved performance.	30sec – 7 minutes *These times apply to networks described as 'good'.*	Within range 55% - 90% *Lower success rates were observed in networks described as 'poor'.*
Wireless LAN - 2.4GHz RF (Radio Frequency) Mesh	This technology was found to be better suited to urban areas. It was stated that most RF Technology is proprietary; this is seen as barrier to standardisation.	30-60 seconds	<71%
Point to point wireless – GPRS over GSM	A proportion of meters (5%) were not covered due to low signal strength. There is a risk that mobile network operators will not support GPRS for the entire lifetime of smart meters. GPRS does not support broadcast/multicast; this is a potential problem for firmware upgrade.	30-90 seconds	99%

Table 2 - Summary of findings from Irish Smart Metering Trials [12]

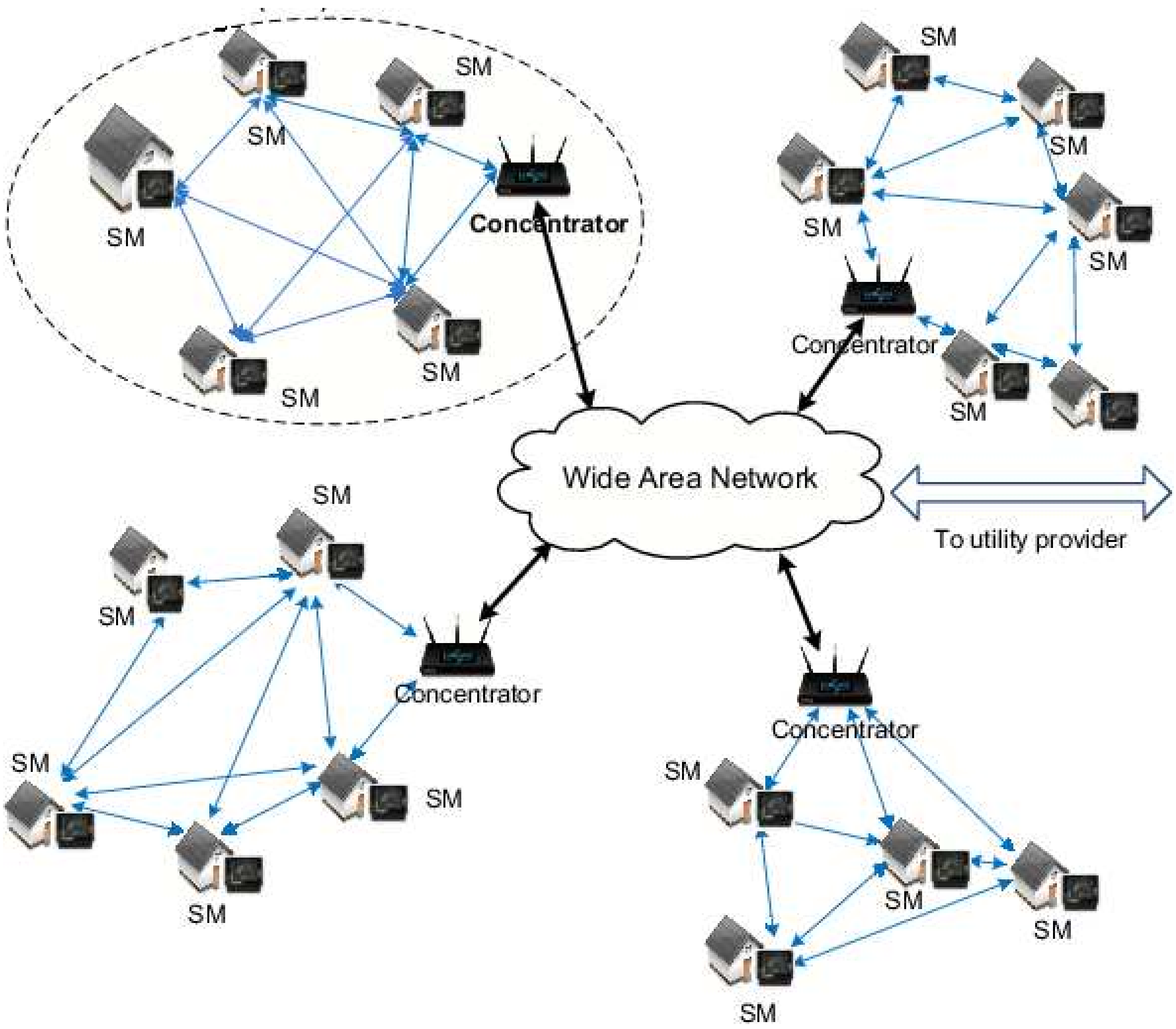


Figure 5 - Use of Local Concentrators with local wireless mesh networks[6]

The European Commission's mandate on interoperability of European smart meters was released in March 2009. The mandate requires the European standards organisations CEN, CENELEC and ETSI to "*create European standards that will enable interoperability of utility meters (water, gas, electricity, heat), which can then improve the means by which customers' awareness of actual consumption can be raised in order to allow timely adaptation to their demands (commonly referred to as 'smart metering')."* The Smart Meter Co-ordination Group was set up to meet this aim. There is some debate within this group as to whether Home Energy Management Systems should be specified by specialists from smart metering or home networking backgrounds.

Three approaches for assessment of communication technologies and topologies in smart metering systems are: practical trials, analytical methods and simulation. Researchers at the University of Bristol are building an erlang based simulation tool for analysis of different communication systems and architectures for smart grid use cases. The simulation includes models of:

- Communications link technologies – backhaul, access, and home
- Communications node processing – distribution of processing capacity and device capabilities
- Distributed concurrent applications – different traffic generation characteristics

The simulator has been used to build a model of example smart metering infrastructure. The model is a collection of simulation actors that interact with each other through the exchange of messages, to simulate the flow of traffic. Two types of actors were employed; the first modelled message processing that takes place in communication nodes, the second modelled the communication links (i.e. the transmission of messages between nodes). A representation of these actors is shown in Figure 6.

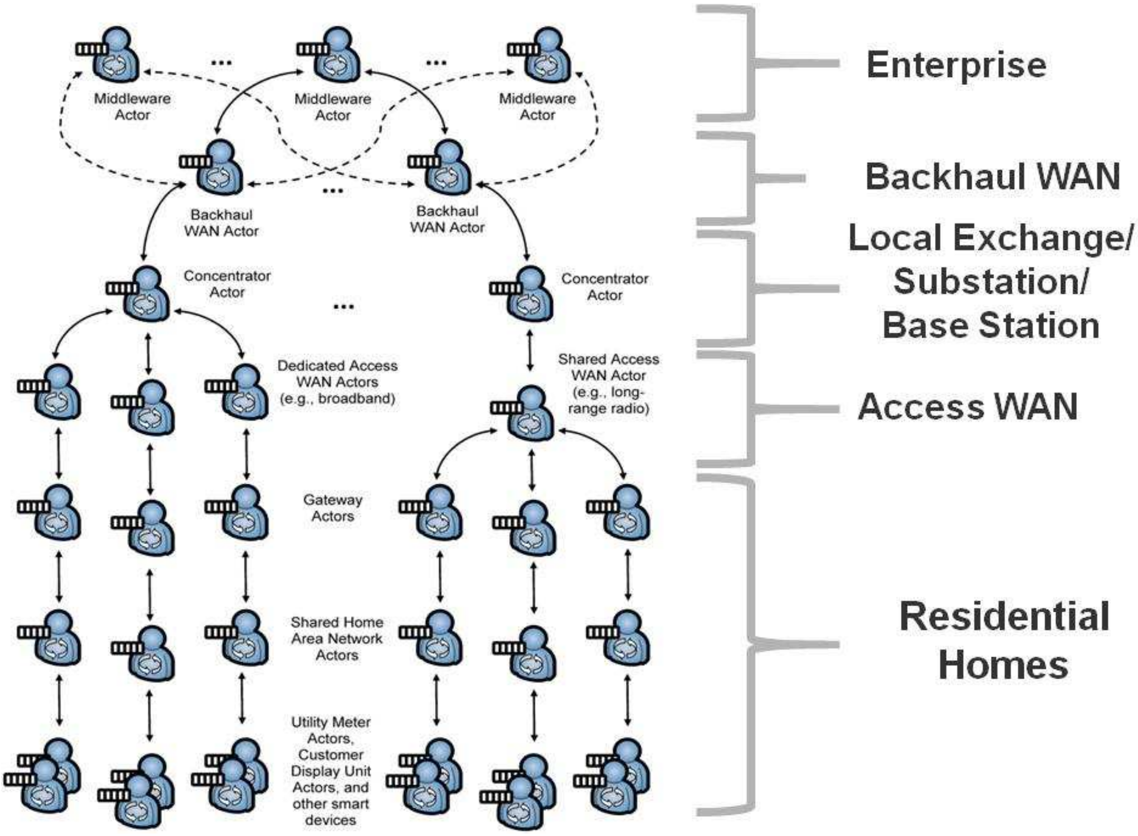


Figure 6 – Simulation actors in a smart metering infrastructure model [6]

The aim of the simulator is to assess transaction/traffic volumes, response times, failure rates and utilisation of communication systems for smart metering infrastructure. The system has been used to model 7200 homes with a Power Line Carrier communication system to simulate and assess message delays and quantity of data moving through the communication system. Also the system has been used to compare message delays for various WAN candidate technologies including PLC, GPRS, broadband and long range radio (see Figure 7).

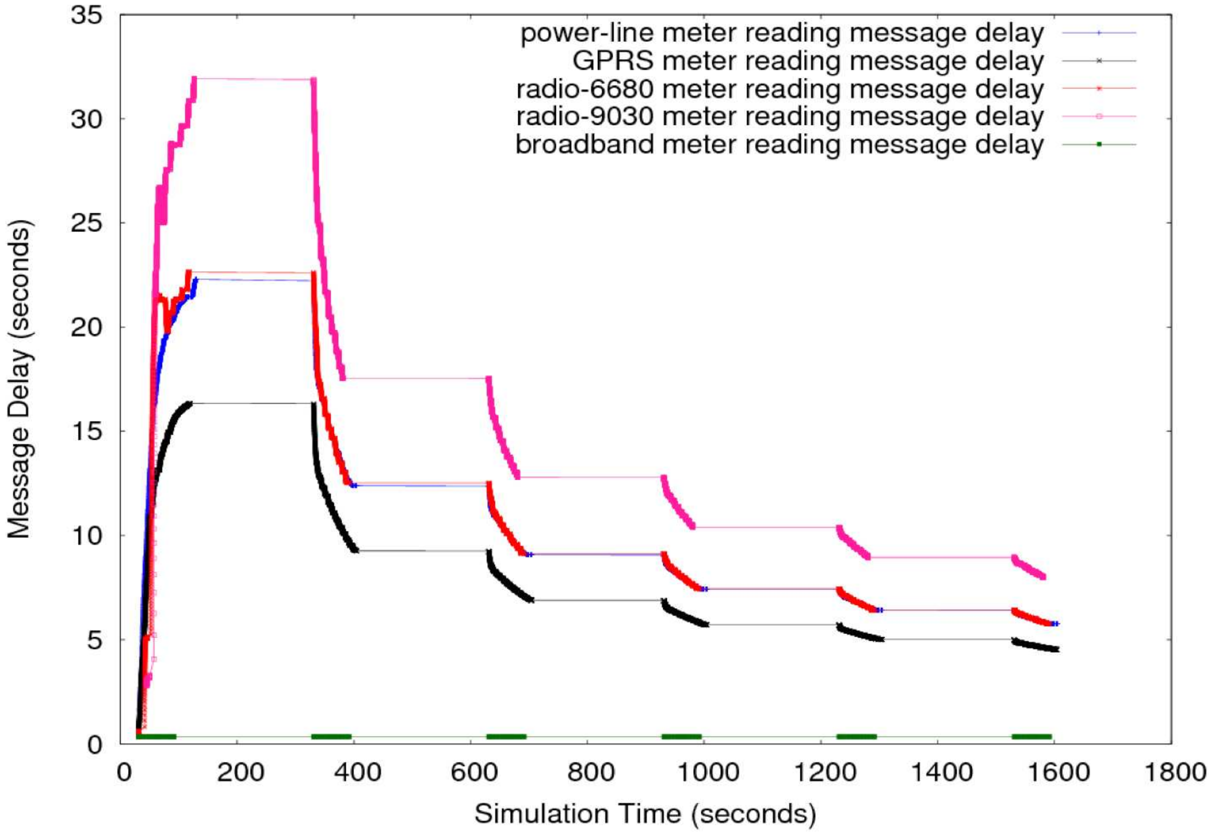


Figure 7 - Simulation output from erlang based smart metering infrastructure model. Comparison of WAN communication technologies.[6]

Smart meter communication events can be categorised as follows:

Autonomous: Those communication events initiated by smart meters (e.g. the sending of a 'last gasp' message to indicate loss of supply).

Interrogation: Those communication events initiated by a centralised entity, with the purpose of reading data (e.g. interrogation of meter to ensure that supply has been successfully restored following an outage).

Control: Those communication events initiated by a central entity, with the purpose of initiating some form of response from the connected loads/generators (e.g. ToU pricing signals).

The timescales over which smart meters must communicate data vary with its intended use. Data for planning uses, such as reconnection scheduling, can be obtained on an ad-hoc basis with no requirement for an immediate response. On the other hand, communication of data for operational purposes is likely to require low latency so that changes in monitored parameters lead to an effective reaction.

5 Smart Meter Hardware

A smart meter can be considered in five functional blocks as indicated in Figure 8. Smart meters work by sampling voltage and current waveforms and then processing the samples to obtain electrical parameters.

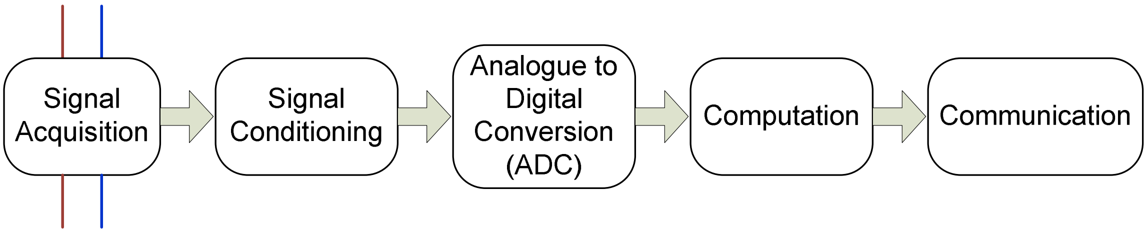


Figure 8 - Smart meter block diagram (Auxiliary items, such as display screen and supply disconnector, have been omitted for clarity)

The functionality of a commercially available meter, deployed in the United States, known as the Elster REX2, includes 128 bit AES (Advanced Encryption Standard) encryption, time-stamping of outage/restoration events, voltage monitoring, remote upgrade and the inclusion of an internal contactor. Its SoC (System on Chip) processor includes a 22-bit delta-sigma ADC with a maximum sampling rate of 3360 Hz. Theoretically, this permits sampling of up to the 33rd harmonic at 50 Hz. However, the 32 kHz clock source (used for both the real-time clock and system clock) and the 4 KB internal RAM represent constraints on the computational capacity of the device[13].

The UK proposals require half-hourly readings, archived for 13 months. Storage of this data would exceed the total internal non-volatile memory of 256 KB available within the Elster REX2 device (assuming a 64 bit double precision variable is used to record import and export values into two data structures, requiring 294 KB). Furthermore, implementation of an TCP/IP stack could result in the use of 988 bytes[14], almost a quarter of the available RAM.

The sampling rate, sampling resolution, processor, memory and architecture limit the parameters that a smart meter can obtain. Furthermore, additional processing and memory capacity is required to perform analysis on the data. For example, a smart meter may need to notify the network operator that a voltage exceeds limits. This function requires continuous conditional testing of input data and would thus increase the burden on a smart meter's CPU (Central Processing Unit). Similar, as yet undeveloped, functions may become apparent after smart meters have become widespread. To allow for future deployment of new applications, smart meters will require adequate sampling rate, sampling resolution, processor, memory and architecture alongside the ability to facilitate the remote upgrade of firmware.

The functional requirements included in the UK proposals indicate that smart meters will allow remote update of firmware. This implies that new algorithms can be deployed after smart meters have been installed. However, the hardware specification for the UK smart meters has not yet been established, so the limitations resulting from the sampling rate and CPU resources are not yet known.

6 UK Smart Metering System Implementation

It is expected that the Data Communication Company (DCC) and associated services will be ready to accept data from SMETS-2 meters by the third quarter of 2014. The DCC will be expected to facilitate access to smart metering data for suppliers, network operators and possibly for other contracted services (see Figure 9). It is possible that a large number of SMETS-1 meters will have been installed by this time. It is likely that suppliers will develop bespoke systems for collection of data from SMETS-1 meters. Therefore, it may not be possible to migrate the SMETS-1 metering data to DCC control, due to vested interests or lack of compatibility. This could create two parallel schemes and increase the overall cost of running the system.

Not all functions requested by advisory groups will fall under the mandate of the DCC. Services provided by the smart metering system can be termed 'mandated', for those under the remit of the DCC, and 'non-mandated' for those outside the remit of the DCC. It is likely that mandated services will include core services such as billing or outage management whereas non-mandated services could include applications for interaction with consumer computers (phones, tablets etc) such as analysis of measured energy usage data, or automatic tariff comparison services.

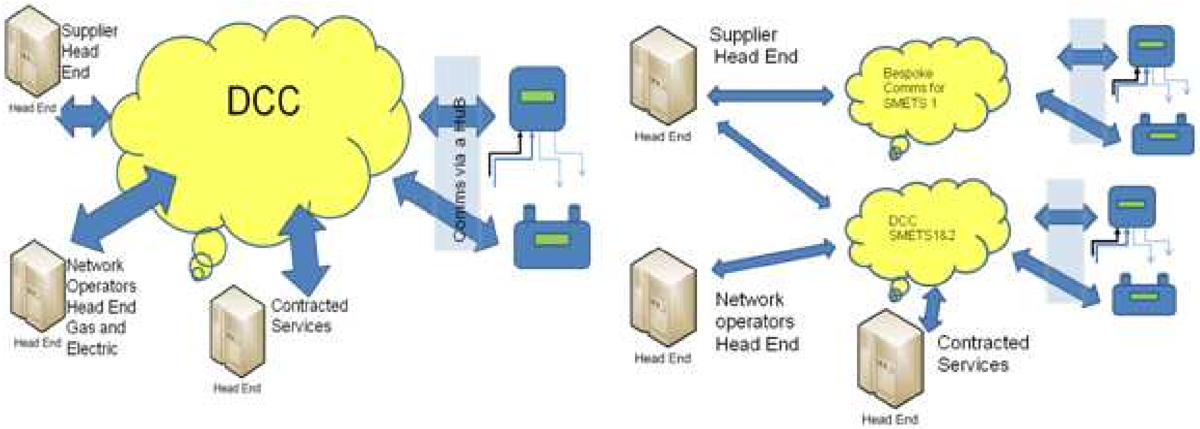


Figure 9 - DCC Envisaged architecture (left) and possible outcome for SMETS-1 and SMETS-2 meters (right) [6]

Industry bodies have suggested a model where smart meter hardware capability (i.e. the sampling rate, memory processor and architecture) is put in place to suit agreed functions. However the software to achieve the functions will not be in place at time of installation and could be purchased at a later date. This approach is similar to the smart phone and application model. In this model smart phones are sold with various capabilities (e.g. communication via GSM, Bluetooth, location detection, orientation detection) but with limited software available to make use of them beyond core functions, such as making calls and management of contacts. Software can be acquired later to make use of the capabilities.

Clearly there are limitations in the applicability of this model to smart metering. An obvious difference is that applications may serve purpose for more than one stakeholder, i.e. network operators and consumers. Potential drawbacks to this approach include the potential for abuse by unscrupulous developers or the underuse of installed hardware capabilities. There is a balance to be achieved between the risk of under specifying the smart meter hardware capabilities (resulting in a reduced overall system capability and inability to realise potential benefits) and the risk of over specifying (resulting in a higher than necessary initial cost).

The cost of smart meter hardware and installation may not be seen by the customers initially; rather meter operator companies may install smart meters and lease them to suppliers, spreading the cost over the meter's lifetime. This approach has the benefit of reducing the initial cost impact of the smart meter roll-out. However the length of such leases and what happens after leases expire is not yet clear.

The UK government has announced that smart meters will not be mandatory. This means that traditional meter reading schemes could remain and the forecast savings will not be realised.

UK proposals include Universal Communication Hubs, for consumer interaction with smart meters, which are to be supplied by the DCC. A potential problem with this approach is contractual responsibility for the smart meters. If a smart meter malfunctions it may be difficult to determine the responsible party, if module components were provided by different companies.

The rollout of smart meters will bring about an increased risk of cyber attacks due to bi-directional communication paths. Security threats to smart meters can be categorised using the CIA triad: confidentiality, integrity and availability[15].

Confidentiality: Relates to the consumer's right to privacy. Centralised collection of data creates a target for attacks aimed at stealing personal information. The Netherlands suspended its smart meter deployment, after the fine-grained collection of users' consumption data was ruled unlawful without consumer consent [16].

Integrity: Relates to the reliability of data. A perceived threat is electricity theft resulting from unauthorised modification of metered data. This might be committed by consumers or by organised criminal entities.

Availability: Concerns the potential vulnerability to an interruption of supply. There is a risk that an attacker could gain control of the system head-end, instruct all meters to interrupt supply by means of their internal contactors and then prevent restoration of supply[17].

7 Use of Electricity Smart Meter for Electricity Networks

7.1 Background

Of the £18.7 billion in benefits predicted to arise from the UK smart meter roll-out approximately 5% have been attributed to networks. This is further broken down into sub-categories as indicated in Figure 10. Over 50% of the forecast network benefits are attributed to reduced losses. These reduced losses may come from improved management of voltage in distribution networks. Little benefit is predicted to arise for gas network operators.

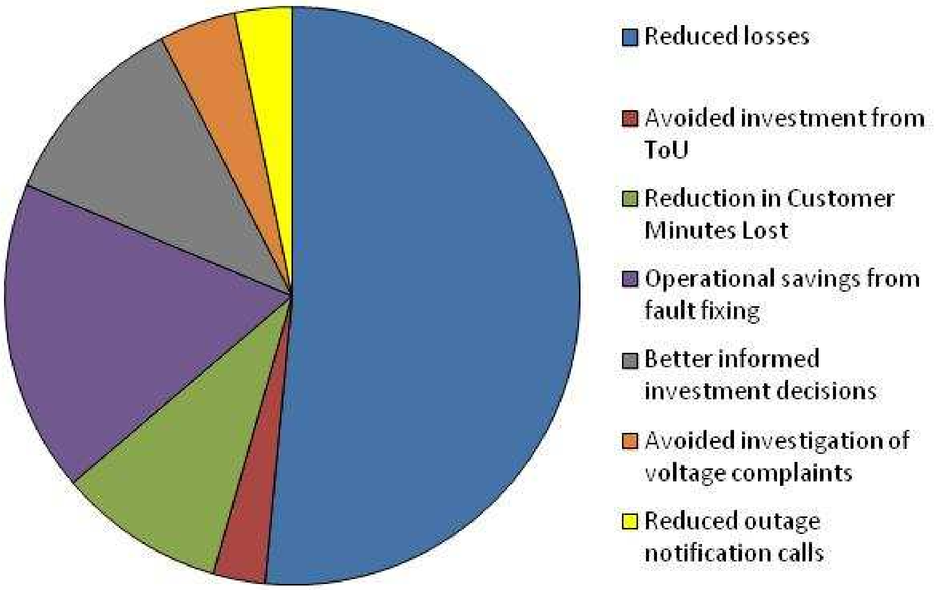


Figure 10 - Benefits from UK smart metering system Impact Assessments attributed to Networks. ToU – Time of Use [tariffs][1]

At present Distribution Network Operators in the UK are paid via Suppliers though Use of System charges. There is a danger that not all of these savings will be benefit consumers. Whilst use of smart metering data could improve system efficiency and reduce energy loss, network operators will not see a reduction in costs as there will be no resultant reduction in asset maintenance costs. Furthermore, if consumers reduce energy consumption as forecasted and network operators do not decrease costs there is a possibility that the cost per unit of energy transferred across the network will increase. However, some benefits, such as improved outage management and better informed investment should result in reduced costs.

7.2 Smart Meters for Network Planning

7.2.1 Profile Analysis

Analysis of load and voltage profiles obtained from smart meters will allow improved asset utilisation in distribution networks. At present, network operators use generic profiles of domestic loads when assessing requirements for new connections and network reinforcement. These load profiles are likely to change in future due to increasing connection of heat pumps and electric vehicles along with more prevalent demand response schemes. Using recorded smart meter data, from an area of the network set to be reinforced, will provide a more accurate basis for prediction of likely future voltage and demand operating ranges. This will enable network designers to specify equipment more accurately, reduce overspending on new equipment and defer or cancel investment in asset replacement.

Smart meter data can be used to rebalance demand across the three phases at distribution feeder points. The take up of demand response, heat pumps and electric vehicles will not be evenly spread across three phases, therefore overloading may occur in one phase. Analysis of historical smart meter demand data will allow network operators to configure phase loading of distribution feeders to maximise asset utilisation.

In European networks, the influence of temperature on voltage and demand profiles will grow as heating technologies such as Combined Heat and Power units (CHP) and heat pumps become more widely deployed. Techniques to predict day ahead demand[18] and voltage[19] based on previous profiles, local temperature forecasts and other data have been put forward. Accumulated smart meter voltage and demand profiles can be used in conjunction with such techniques to predict local network conditions.

7.2.2 Reconnection Scheduling

Historical smart meter data will enable network operators to estimate future demand for particular areas of their networks. This capability can be used to plan staged reconnection schedules in preparation for re-energisation following a blackout[20]. In the UK, smart meters will be fitted with contactors for remote disconnection/re-connection; these could be used to implement a pre-planned re-connection schedule.

Awareness of latent demand (demand which is hidden from network operators by the operation of microgeneration) allows network operators to plan reconnection schedules with greater confidence. Latent demand data can be obtained from smart meters by combining consumption data with generator output data gained from dedicated generator meters.

7.2.3 Condition Monitoring

Consistently high current at or near to equipment ratings can cause degradation of equipment. However, cabling and transformers typically have temporary overload ratings so that current ratings can be exceeded without degradation for a limited time. Knowledge of peak current magnitudes and durations gained from smart meters, combined with record information such as cable types, soil properties and temperature limits can allow network planners to postpone or avoid investment without significantly compromising supply reliability or cable life span[21].

7.2.4 Power Quality Monitoring

Smart meters can monitor voltages and communicate the nature of voltage excursion events. This can help network operators find the source of voltage problems and plan actions to mitigate. Voltages at customer's points of connection must lie within predefined limits. The IEEE classifications, of events where voltages move outside operating limits, are summarised in Figure 11.

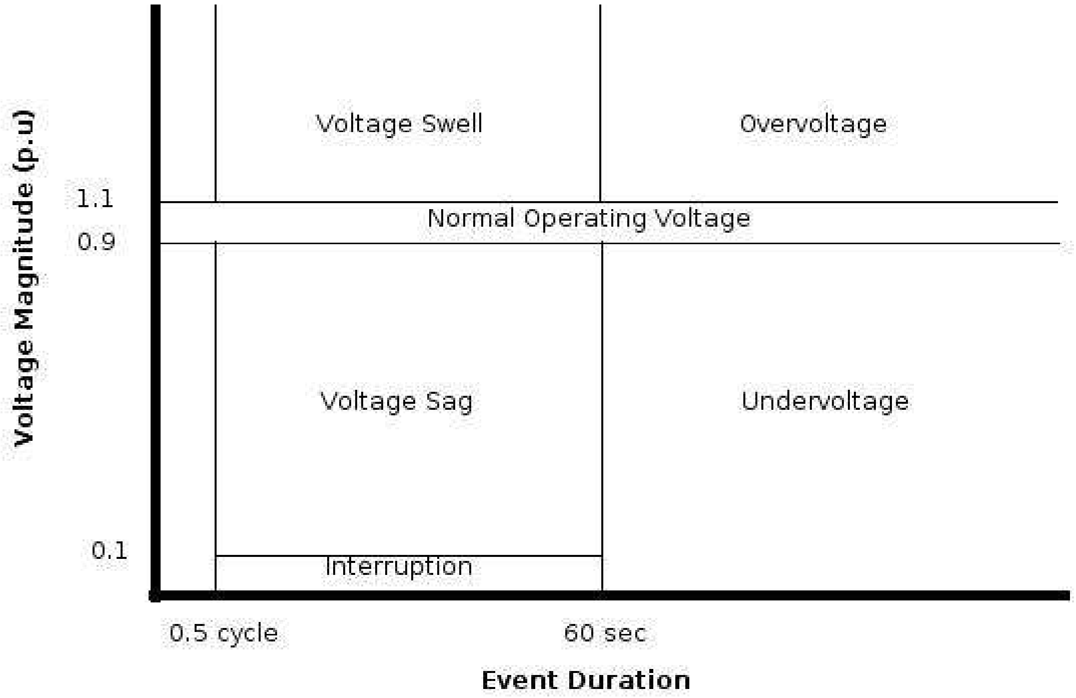


Figure 11 - Definitions of voltage magnitude events as used in IEEE Std. 1159-1995 [22]

Harmonic distortion of the voltage and current waveforms, brought about by non-linear loads, can have an adverse effect on distribution transformers and cause decreased efficiency through heat loss. An increase in non-linear loads such as fluorescent lighting, electric vehicle chargers and heat pumps may exacerbate these problems. Using smart meter data to flag harmonic and flicker problems as they arise could help trace their sources and enable swift resolution with connected users. Moreover, smart meters can be used to verify that such problems have been corrected.

It is not clear whether UK smart meters will be capable of detection of all harmonics (UK guidelines prescribe limits up to the 50th harmonic). The requirement to record Total Harmonic Distortion (THD) was removed in DECC's 2011 consultation response. Similarly there is, as yet, no defined specification for measuring power quality events.

7.3 Smart Meters for Network Operation

5.1 Outage Management

Use of smart meters can improve outage location and supply restoration times. Traditional outage management methods are based around customer calls. It has been shown that polling a limited number of smart meters during an outage can help locate faults[23]. Furthermore, using smart meters, network operators will have the ability to confirm the reinstatement of disconnected supplies. This approach can reduce reliance on customer calls and therefore improve supply restoration times.

5.2 Voltage Monitoring and Control

Increased penetration of distributed generation can result in voltage rises above limits at distribution feeders. This problem can be alleviated using active voltage control, which is typically achieved using one or more of the following methods:

- On load tap changers (OLTCs);
- Reactive power control;

- Curtailment of loads/generators.

In traditional networks, distribution transformers have a fixed turns ratio or have off-load taps. Introducing OLTCs at distribution level, in combination with active control based on monitored voltage levels from smart meters, can reduce voltage excursions outside limits. Therefore the capacity of distributed generation can be increased[24].

Reactive compensation typically involves the staged introduction of shunt capacitance at given points on the network. Standard methods for control of switched banks of capacitors are based on voltage, current, kVAr, time or temperature[25]. In conjunction with reactive power profiling, monitoring of the power factor by smart meters can help network operators to decide optimum points for connection of capacitor banks and provide a basis on which to control such systems.

Power system state estimation algorithms typically estimate voltages and phase displacements throughout a network based on a range of available information. From this, optimum network configurations can be selected to minimise losses. Distribution network voltages can be reliably estimated using previous-day smart meter data to supplement relatively few upstream measurements. Accurate voltage estimations can be used by distribution management systems to provide network voltage control. However, as load profiles become less predictable (due to the influence of demand response, heat pumps and electric vehicles) voltage estimation will become less accurate. Therefore, state estimation algorithms will require near real-time smart meter measurements (e.g. less than half hourly communication intervals) in order to allow active voltage control.

7.3.1 Distribution network state estimation

Power system state estimation algorithms typically approximate voltages and phase displacements throughout a network based on a range of available information. Power flows between nodes can be calculated from this and optimum network configurations selected to minimise losses. Distribution network voltages can be reliably estimated using previous-day smart meter data to supplement relatively few real-time measurements[26].

7.4 Smart Meters and Demand Response

7.4.1 Background

Demand Response (DR) techniques represent a means to flatten peaks in demand, therefore improving asset utilisation. Furthermore, DR techniques can ensure that demand reacts to changes in energy supply, thus allowing increased penetration of fluctuating generation. Numerous methods exist for bringing about a response (i.e. a deviation from normal usage) in demand, see Table 3.

Table 3 - Classification of Demand Response (DR) methods[27]

Incentive Based	**Price Based**
Classical	Time of Use (ToU)
Direct Control	Critical Peak Pricing (CPP)
Interruptible/Curtailable Load Agreements	Extreme Day CPP (ED-CPP)
Market Based	Extreme Day Pricing (EDP)
Demand Bidding	Real Time Pricing (RTP)
Emergency DR	
Capacity Market	
Ancillary Services Market	

7.4.2 Distribution Network Constraints

Smart metering systems are seen as a precursor to widespread implementation of demand response. Smart meters in the UK will support demand response through communication of pricing levels to users, alongside provision for incentive based schemes such as direct control. As consumer take-up of DR schemes rises, there are likely to be imbalances in participation across different phases, distribution substations and wider areas. There are three main issues which may lead to voltage excursions and reduced effectiveness of demand response[28]:

- Cold-load pickup effect on demand response release;
- Co-ordination between DR and distribution system volt/var control;
- Unbalanced DR spread across phases.

To lessen the impact of the problems, network operators can be given the means to influence DR schemes. In the UK, customers pay for distribution network operation, via their Suppliers, with DUoS (distribution use of system) charges. Proposals have been put forward to include a dedicated register within smart meters so that pricing based schemes can be influenced by the limitations seen by distribution network operators. However, in general, the way in which network operators and DR schemes should interact remains largely undefined.

7.5 Other

7.1 Frequency Response

Smart meters can be used to detect frequency and co-ordinate loads in order to provide primary frequency response[29]. However, the ability of commercially available smart meters to monitor and react to frequency is not universal. Furthermore, the requirement for smart meters to monitor frequency was removed in the UK's revised proposals of March 2011.

7.2 Energy Use Reduction

Decreasing the voltage applied to a load can reduce energy use. By using smart meter voltage readings and controlling supply voltages network operators will be able to minimise overall energy use. To achieve this, equipment settings (such as transformer tap settings) can be adjusted to optimise the supply voltage.

7.6 Smart Metering Electricity Network Functions

As can be seen in Figure 12, the UK proposals do not explicitly call for all of the smart metering system functions likely to be of benefit to network planners and operators. The ability to introduce the omitted items in future, such as support for active voltage control, depends on the sampling rate, data processing capabilities and communication limits of the smart meters. Finally, other issues, such as concern surrounding information privacy and security, may limit the performance of electricity network control using smart meter data.

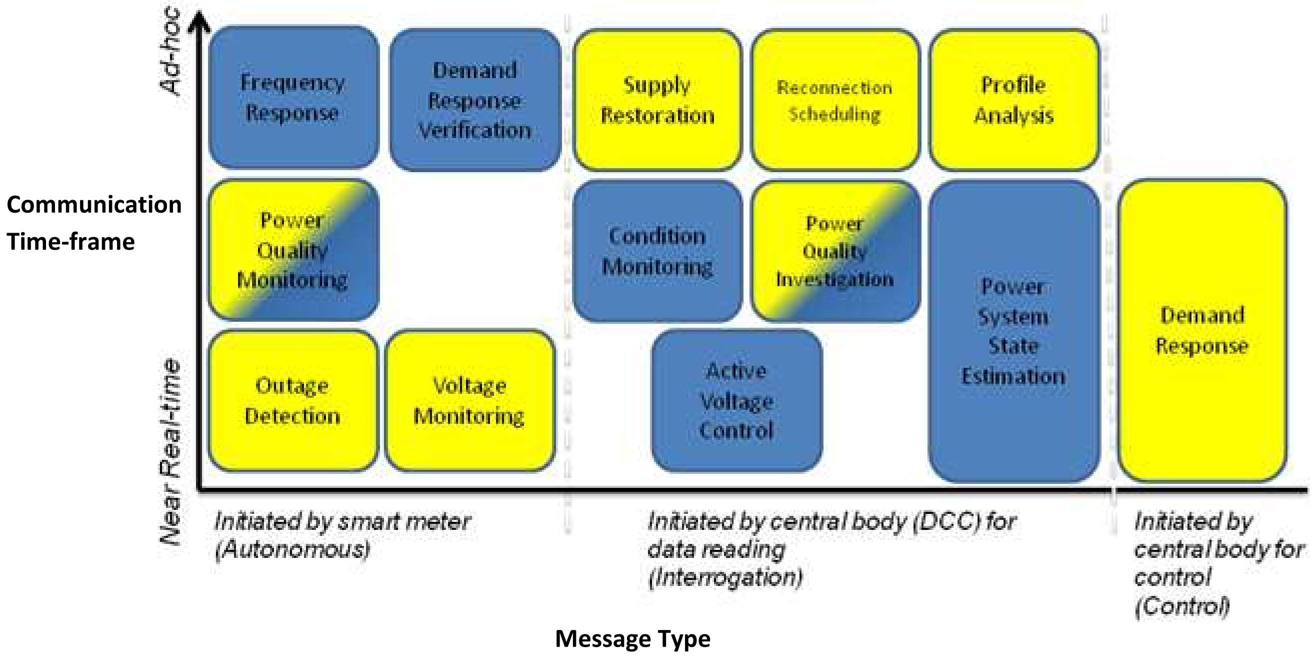


Figure 12 - Uses of smart meters for electricity networks. Functions are classified by type and time-frame of associated messages. Yellow indicates inclusion in UK proposals, Blue indicates that it is not included. Note power quality related functions have partial inclusion as the requirement to measure frequency and total harmonic distortion is not included whilst voltage deviations are monitored.

8 Ongoing Research

8.1 Distribution Network Control

Investigation of the use of smart meters for voltage control in distribution networks is ongoing. The use of smart meters, based on predicted availability of data for the UK system, to estimate distribution network voltages has been undertaken. It was found that the accuracy of the state estimation algorithms was improved by supplementing the readings with relatively few near real-time voltage measurements. Building on this, research is underway to investigate the applicability of smart meter data to distribution network voltage control techniques such as on load tap changers and reactive power compensation.

Research into how state estimation and a soft computing network reconfiguration algorithm can be combined to form an integrated supply restoration scheme for the Medium Voltage (MV) network is in progress. The scheme utilises smart meter data, offers flexibility in implementation and has the potential to incorporate Smart Grid technologies such as Demand Side Management. A real-time closed loop research platform has been developed to facilitate this research. It simulates MV networks and provides an interfaced network controller environment to run the research algorithms on.

8.2 Demand Side Integration

The role of the consumer is likely to be influential in providing a demand response to fluctuating supply conditions. The extent and flexibility of existing and future domestic electricity load is being examined, and how management of this load can improve system efficiency. Areas being addressed include behaviour theory; automatic and reflective processes when engaging in energy consuming practices; attitudes towards, and acceptance of, appliance automation; incentives and signals; appliance and load categorization; the role of storage; distributed and micro generation; and alternative energy vectors.

Research into the optimisation of domestic appliances operation using constraints such as: the total system generation availability (reflected by a pricing signal), the local network capacity and user requirements is ongoing. Detailed assessment of appliance operation will be undertaken, with review of pricing signals and user responsiveness for various scenarios. The impact that such optimisation techniques, if scaled to a national level, will have on the overall electricity system is to be estimated.

For customers to provide demand response it must be visibly rewarded (or made mandatory – this approach is unlikely to be taken). Some techniques achieve this by allowing the customer, or customer’s appliances, to respond to demand response pricing signals. Another approach is to record and quantify customer’s changes in demand following a request for a reduction (or increase) in energy use. Demand response actions can then be retrospectively verified and rewarded. Alternatively customers can be paid to agree direct load control by aggregators. Verification data can then be used to demonstrate demand response to central system operators. By monitoring participation network operators can prepare for and limit the impact of demand response. Investigation of methods to achieve demand response verification and validation is underway.

The use of smart meters to bring about distributed primary frequency response has been demonstrated. An appliance control scheme was implemented based on frequency readings from a commercially available smart meter. It has been noted that the requirement to monitor frequency has been removed from the UK consultation documents.

8.3 Other Work

This paper draws information from the Smart Metering Colloquium held at Cardiff University on the 8th February 2012. The authors would like to thank all who participated.

9 Open Research Questions

There are many open research questions relating to smart metering. Related research topics include; energy use reduction, demand response, cyber security, electricity network planning and operation, active network control and demonstration/comparison of technologies. A list of topics, with example research questions, is shown below:

1. Energy Use Reduction
    a. Will energy use reduction persist over long term?
    b. Will there be a rebound effect?
    c. How can distribution network losses be reduced using smart meter data?
2. Demand Response
    a. How should the aims of demand response (supply/demand balancing, voltage control and improved asset utilisation) be balanced?
    b. What is the local network impact of centralised demand response schemes?
    c. What forms of demand response are acceptable to all parties (i.e. consumer, DNO and TSO)?
    d. Should smart meters be capable of responding to system frequency?
    e. How can smart meters be used to verify demand response operation?
3. Cyber Security
    a. How can the smart metering system be made resistant to attack?
    b. What are the security risks?
4. Network Planning and Operation

    a. Can smart meters be used to precisely locate faults?
    b. Is it possible for network operators to access smart meter data without invasion of consumer privacy?
    c. What techniques can be used for analysis of smart meter data?
    d. Can smart meter data be used to ascertain the influence of external factors (e.g. weather, entertainment schedules, traffic activity) on energy supply.
5. Electricity Network Control
    a. How can smart meter data be used for localised voltage control or network re-configuration?
    b. What sampling rate and communication rates are required?
    c. How can control philosophies be compared (e.g. centralised vs decentralised)?
    d. How can the value of active control be quantified?
6. Energy storage
    a. How should smart meters interact with energy storage technology?
7. Public Acceptance
    a. How can the balance between consumer data privacy and use of data by third parties be addressed?
8. Technology
    a. What are the most suitable communication standards?
    b. How should data be stored?
    c. Will smart meter enable the use of alternative technologies?
    d. What sampling rate should the smart meters use?
    e. How much data should each smart meter store?
9. Other
    a. Can smart meters be used for purposes other than those originally intended (e.g. activity monitoring of elderly/infirm)?

Demand Response schemes have several potential benefits. The foremost examples are; bringing about improved asset utilisation, balancing of system supply and demand and removing connection limitations for localised generation. In some circumstances these aims may conflict. Research is required to ascertain the value of each and to achieve co-ordination between them.

The interaction of smart meters with active distribution network control has not been well defined. Active control of distribution networks has the potential to improve asset utilisation in distribution networks. It involves the co-ordinated control of active devices (such as automatic tap changes) and could include interaction with demand. However, there is no consensus on the most suitable control philosophy and the data/communication requirements.

Research into security of the smart meter communication system is of high importance. The roll-out of smart meters will increase the risk of cyber attack on the UK electricity network. As UK smart meters are fitted with supply contactors, a situation where all domestic supplies are remotely disconnected is possible. The resulting unexpected drop in load could cause system stability problems. Review of 79 known research projects funded by organisations such as EPSRC, TEDDI, TSB, LCNF, UKERC and the EU FP7 framework indicated relatively little active research in this area.

The roll-out of smart meters will result in network operators having access to large amounts of data. There is a significant challenge in finding ways to visualise large amounts of data in a way that is useful to network operators for both planning and operation. Also, it is not known, in detail, how external factors (such as weather, entertainment schedules and traffic patterns) influence demand and thus the operation of networks. Research into this area could provide a basis on which to accurately predict local demand and schedule switching operations.

A review of UK and EU research projects was undertaken. The review involved collation of details (funding body, summaries, duration, start date and budget) for 79 known research projects funded by organisations such as EPSRC, TEDDI, TSB, LCNF, UKERC and the EU FP7 framework. After review of the project summaries, the research projects were attributed to one or more of the 7 categories as shown in Table 4. The full list of projects can be found in Appendix II.

As can be seen in Table 4, the category with the least number of projects is 'Policy, Regulation and Business Cases'. This is expected as the development required is of the sort typically undertaken by Government departments. Indeed, the UK Smart Metering policy and regulation developments are being led by DECC.

Table 4 – UK/EU research projects categorised by project aim. The number of applicable UK projects was taken from a list of EPSRC, TEDDI, TSB, LCNF, DECC projects (see Appendix II). The project aims were categorised based on available project summaries.

Aim of smart metering projects:	Number of applicable projects:
Achieve reduction in energy usage	35
Achieve increased connection of low-carbon generation and improved asset utilisation.	35
Understand Public Acceptance	18
Assess Policy, Regulation and Business Case	6
Develop, Demonstrate and Review System architecture and technology	30
Field Trials	13
Other	7

It is likely that smart metering research questions will be addressed in parallel with the UK smart meter roll-out. A challenge for all stakeholders, including government, industry and academia, is to ensure that research lessons can be applied without disruption to the programme.

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Appendix I – Hubnet Colloquium Cardiff University – Programme:

HubNet
The Supergen Energy Networks Hub

HubNet SMART METERING COLLOQUIUM

SMART METERING FOR NETWORK PLANNING & OPERATION

Wednesday 8 February 2012

Objective

The roll-out of smart meters in the UK is due to formally commence during 2014 with a view to completion in 2019. Over 53 million meters are planned to be installed in around 30 million homes and small businesses at a total cost of £11.7bn. Smart meters are expected to deliver a range of benefits to different stakeholders with energy networks having better information upon which to manage and plan their activities, leading to the development of a smarter electricity system.

The HubNet Smart Metering Colloquium is being organised to promote the exchange of ideas between researchers and between researchers, industry and the public sector on how smart meters can be utilised to improve network planning and operation, and to highlight key issues and future research challenges. An in-depth position paper will be prepared as one of the formal outputs from the event.

The Colloquium is organised by HubNet, the Engineering & Physical Sciences Research Council funded hub for energy networks, which has been established to catalyze and focus the research on energy networks in the UK.

Programme

09:30	Registration and refreshments
10:00	Welcome and introduction to day • Professor Nick Jenkins, Cardiff University
10:10	Keynote Smart Metering – Destination or Journey? • Tony Taylor, Utility Partnership Limited
10:40	What is a smart meter and what is it for? • Brian Drysdale, Cardiff University Smart meters: the consumer perspective • Lindsey Kearton, Consumer Focus
11:30	Cyber security and privacy • Tim Parkins, Cassidian Smart Meter Security Survey • Alasdair Burchill, Cardiff University

12:30	Lunch
13:30	Keynote Smart Meter Migration to DCC • Andrew Smith, BGlobal
14:00	Smart Meter Communications Mesh Radio Solution & UK/EU Architectures • Dr Mahesh Sooriyabandara, Toshiba Research Europe Ltd End-to-End Performance Evaluation of Integrated Smart Energy Solutions Through Large-Scale Simulations • Dr Terence Song, University of Bristol
15:00	Use of smart meters for electricity networks • Lee Thomas, Cardiff University Use of smart meters for frequency and voltage control • Kamalanath Samarakoon, Cardiff University
16:00	Conference close and refreshments

Presenter Biographies

Professor Nick Jenkins

Nick Jenkins is the Director of the Institute of Energy within the School of Engineering at Cardiff University. Before moving to academia, his career included 14 years industrial experience, of which 5 years were in developing countries. His final position in industry was as Projects Director for Wind Energy Group, a manufacturer of large wind turbines. While at University he has developed teaching and research activities in both electrical power engineering and renewable energy. He is a Fellow of the IET, IEEE and Royal Academy of Engineering. From 2009-2011 he was the Shimizu Visiting Professor to the Atmosphere and Energy Program at Stanford University.

Tony Taylor

Tony Taylor is Business Development Director at UPL who provide utility and energy management services across the UK and in Europe and are an accredited meter operator and data collector with almost 50,000 AMR meters installed. Tony plays an active role in the DECC smart metering programme participating in a number of expert groups. Tony started with the South Wales Electricity Board in 1978 as a student apprentice and later worked in Metering and Energy Utilisation. Subsequent experience included power systems contracting with Hyder/Inframan and FM services with Norland.

Brian Drysdale

Brian Drysdale is currently researching a PhD on demand side management in the Institute of Energy at Cardiff University. His research interests include the policy drivers affecting the electricity sector as well as the role technology plays in influencing consumer behaviour within a balanced system. This involves exploring future supply mixes, and their respective characteristics, and considering how different demand behaviours can be aligned with these supply characteristics to deliver energy policy objectives. Prior to recommencing his academic studies he enjoyed extensive experience in industry, most recently as regional managing director of a national construction group and as chairman of their sustainability consultancy. Brian was awarded an MSc in Sustainable Energy & Environment (Distinction) in 2010, a Master of Business Administration (MBA) in 1994 and a BSc in Quantity Surveying in 1986. He remains a member of the Royal Institution of Chartered Surveyors (MRICS) as well as holding student memberships of IEEE, BIEE, IET and the Energy Institute.

Lindsey Kearton

Lindsey Kearton is a Policy Manager for Consumer Focus Wales (CFW) – the statutory consumer body for Wales. She has been working in consumer advocacy since 2003 and currently leads CFW work programmes on

energy issues (including fuel poverty) and financial inclusion. Along with NEA Cymru, CFW are co-founders of the Fuel Poverty Coalition Cymru. Both organisations also provide joint support to the Cross Party Group on Fuel Poverty. She is also a member of the Welsh Government's Financial Inclusion Delivery Group.
Her career includes nearly ten years experience in a commercial market research environment where she managed a wide range of projects in both the public and private sector. She is also an associate member of the Market Research Society.

Tim Parkins
Tim Parkins is UK Cyber Sales Manager at Cassidian.

Alasdair Burchill
Alasdair received an undergraduate degree in Electronic Engineering from the University of Surrey. His industrial specialization includes Linux system development including embedded systems, and temporary and permanent power distribution system design and installation. He is also experienced in the use of CAD for both electronic and mechanical design. Alasdair is pursuing a PhD at Cardiff University. He has developed a hardware smart metering test bed for the purpose of examining the communication and security requirements, and implications, of using smart meter technology for distribution network control.

Andrew Smith
From January 2012, Head of Smart Metering Systems for Bglobal plc. Programme manager for Secure Meters for 4.5 years, specialising in Smart Gas metering and developing the first Smart Metering Systems for deployment within the Ofgem EDRP initiative. From 2010 an active consultant for the Smart Meter program at the working group stage and generation of the IDTS/ESoDr document(s) in 2011. Has remained active within the DECC SSAG forum. Engineering Manager at Siemens Metering Systems at the Oldham site prior to the merger with Landis +Gyr. Responsible for the design of pre-payment metering products(Card, Key) and the design and development of the world's first Ultrasonic Gas Meter. Operations and Engineering Director of Siemens/Plessey Environmental Systems. Responsible for the development and deployment of products and wide area systems, predominantly in the UK and USA for the management of personal health data relating to exposure to ionising radiation in Nuclear Power Plants, Military and civil installations. Holds a Bachelors degree in Applied Physics from University of Lancaster, an MSc in Electronic Systems Design from University of Huddersfield and an MBA from the management school of Bath University

Dr Mahesh Sooriyabandara
Dr. Mahesh Sooriyabandara is Associate Managing Director at Telecommunications Research Laboratory, Toshiba Research Europe Limited (TREL) in Bristol, UK. He has worked in academia and industry as a lecturer, researcher and manager of many successful ICT R&D & Pilot projects related to next generation wireless networking, reconfigurable device architectures and 'smart' systems for energy and communications. Mahesh has authored over 40 publications and several patents. He is an active participant and contributor of several standardization activities within IETF, ETSI and IEEE. He is a Senior Member of the IEEE, Senior Member of the ACM, and a Chartered Engineer and a member of the IET.

Dr Terence Song
Dr Terence Song received his PhD in 2007 from the University of Bristol, for his research in the area of Network Visualisation, Control and Management. He has contributed to various research activities and projects, including the Software-based Systems workpackage of the Mobile VCE; the Production of Broadcast Content in an Object-Oriented IP-Based Network; and more recently, the Performance Optimisation workpackage in Project CLEVER (Closing the Loop for Everybody's Energy Resources). He is currently a Research Assistant in Networked Energy Management at the University of Bristol's Centre for Communications Research, working on the simulation and performance optimisation of very large-scale distributed systems.

Lee Thomas
After graduating from Cardiff University (MEng Electrical and Electronic Engineering) in 2004, Lee worked as a Building Services Engineer for Arup and Capita Symonds. His role included the assessment and design of electrical distribution systems for buildings and campuses. Lee joined the Institute of Energy as a Research

Assistant in February 2011. His research area includes the study of how the proposed UK smart metering system can be used to improve electricity network planning and operation.

Kamalanath Samarakoon

Kamalanath Samarakoon received the B.Sc. degree in electrical and electronic engineering from the University of Peradeniya, Sri Lanka in 1991 and the M.Eng. in computer science from Asian Institute of Technology, Thailand in 1996. He is currently working toward the Ph.D. degree in the School of Engineering, Cardiff University, U.K. He joined Ceylon Electricity Board (CEB), the public power utility of Sri Lanka, in 1992 as an Engineer and worked 15 years in the areas of hydro power plants rehabilitation, maintenance, instrumentation and control and as a Chief Eng0ineer (IT). For the research and development carried out in CEB, he was awarded two national awards in 2000 and 2006. He joined the Department of Computer Engineering, University of Peradeniya as a Senior Lecturer in 2007. Since 2009, he has been working as a Research Assistant at Cardiff University. He is a Chartered Engineer in Sri Lanka and in the U.K. and a Member of the IET, IEEE and IESL.

Appendix II – Collated UK and EU research projects relating to Smart Metering and Smart Grids

Project title	Funding Body	Start Date	Duration (months)	Reduction of Energy Use	Inc. Conn. Capacity for Renewables / Asset Utilisation	System Architecture and Technologies	Public Acceptance	Trials	Policy/Regulatory and Business Case	Other
Applied Research into Appliance Level Smart Metering over Broadband	TSB	08/2010	6	1			1	1		
Demonstrating and measuring the impact of smart meters in smart homes in Derby	TSB	08/2010	6	1			1	1		
Smart DC microgrids for homes that shift and reduce energy demand	TSB	08/2010	7		1		1	1		
Project HAWCS - Heating And hot Water Control over the Smart meter infrastructure	TSB	08/2010	6	1			1			
Smart Homes Integrating Meters Money & Energy Research (SHIMMER	TSB	08/2010	6		1		1	1		
Monitor, Manage, Control	TSB	08/2010	6	1			1	1		
TAHI3ID@BRE - TAHI Integration, Interoperability, Installation Demonstrator	TSB	08/2010	6	1						
DIMMER: Domestic Interoperable Metering and Management of Energy and Renewables	TSB	08/2010	6	1			1			
Service Aggregation for Smart Homes (SASH)	TSB	08/2010	6	1						
Concierge	TSB	08/2010	6	1			1			
Volcan: a heating and gas graphic information system	TSB	08/2010	6	1						

Project SMaRT - Action (Smart Metering and Real Time Action	TSB		6	1			1	1		
Smart Village	TSB	08/2010	7	1			1			1
Evaluating the Impacts, Effectiveness and Success of (DECC)-funded Low Carbon Communities on Localised Energy Behaviours (EVALOC)	ESRC: RCUK Energy and Communities Programme	01/2011	42	1			1			
Sustainability Invention and Energy Demand Reduction: Co-designing communities and practice	RCUK Energy and Communities Programme	01/2011	36	1		1				
Smart Communities: Shaping new low carbon communities norms and practices	RCUK Energy and Communities Programme	01/2011	36	1			1			
Reduction of Energy Demand in Buildings through Optimal Use of Wireless Behaviour Information (Wi-be) Systems	EPSRC-TEDDI	10/2010	29	1		1				
C-AWARE: Enabling Consumer Awareness of Carbon Footprint through Mobile Service Innovation	EPSRC-TEDDI			1					1	
Intelligent Agents for Home Energy Management	EPSRC-TEDDI	11/2010	36	1		1				
Advanced Dynamic Energy Pricing and Tariffs (ADEPT) -	EPSRC-TEDDI	03/2011	36	1					1	
Taking on Teenagers – Using Adolescent Energy to Reduce Energy Usage	EPSRC-TEDDI	10/2010	36	1			1			
Multiscale Modelling to maximise Demand Side Management	EPSRC-TEDDI	09/2010	36		1	1				
REDUCE: Reshaping Energy Demand of Users by Communication Technology and Economic Incentives – University of Surrey	EPSRC-TEDDI	10/2010	36	1					1	
LEEDR: Low Effort Energy Demand Reduction	EPSRC-TEDDI	10/2010	43	1						

Carbon, Control and Comfort: User-centred control systems for comfort, carbon saving and energy management	EPSRC	04/2009	41	1		1	1			
Charm	EPSRC	09/2009	29	1			1	1		
Community Innovation for Sustainable Energy		10/2010	36		1				1	
Energy Demand Research Programme	DECC	2007	42	1	1		1	1		
Peak Energy Usage	DECC/DEFRA			1				1		
UNLOC Understanding Local and Community Governance of Energy (UKERC)	UKERC			1			1		1	
OPENMeter	FP7	2009.01	30	1	1	1				
INTEGRIS - INTelligent Electrical Grid Sensor communications	FP7	2009.09	34		1	1				
INTEGRAL - Integrated ICT-platform based Distributed Control (IIDC) in electricity grids with a large share of Distributed Energy Resources and Renewable Energy Sources					1	1				
HiPerDNO - High Performance Computing Technologies for Smart Distribution Network Operation	FP7	02/2010	36		1	1				
DLC-VIT4IP - Distribution Line Carrier - Verification, Integration and Test of PLC Technologies and IP Communication for Utilities	FP7	2010.01	36		1	1				
E-Price	FP7	2010.02	36		1					
MIRABEL		01/2010	36		1	1				
NOBEL - Neighbourhood Oriented Brokerage ELectricity and monitoring system		2010.02	30		1	1				

OpenNode		2010.01	30		1	1				
Web2Energy	FP7	2010.01	36		1	1				
SmartHouse/SmartGrid				1	1	1				
ICT4SDG - ICT for Smart Distributed Distribution	ICT-PSP				1				1	
SEESGEN	ICT-PSP			1						
CASCADE - Complex Adaptive Systems, Cognitive Agents and Distributed Energy	EPSRC	10/2009	42			1				
Smart Grid Oscillation Management ofr a changing generation mix	EPSRC				1					
REDLINE - Reducing Energy Demand Through Large-Scale Integrated Energy Management Systems	EPSRC			1						
RAVEN: Resilience, Adaptability and Vulnerability of complex Energy Networks	EPSRC	05/2010	36			1				
Mathematical foundations for energy networks: buffering, storage and transmission	EPSRC	01/2011				1				
CIREGS: Centre for Integrated Renewable Energy Generation and Supply	EPSRC/ Cardiff Uni	01/2008	60		1	1				
The Autonomous Power System	EPSRC	10/2011	54		1	1				
Intelligent Agents for Home Energy Management	EPSRC	11/2010	36	1			1	1		
HubNet: Research Leadership and Networking for Energy Networks	EPSRC	01/2011	60							1
ARIES - Adaptation and Resilience In Energy Systems	EPSRC	09/2011	41			1				

INTERNET - Intelligent Energy Aware Networks	EPSRC	06/2010	60		1	1				
RESNET - Resilient Electricity Networks for Great Britain	EPSRC	09/2011	48			1				
Replication of Rural Decentralised off-grid Electricity Generation through Technology and Business Innovation	EPSRC/ DFID	10/2009	60							1
Techniques for Electric Power Systems with High Penetrations of Renewable Non-Thermal Generation	EPSRC	04/2009	48		1					
Transformation of the Top and Tail of Energy Networks	EPSRC	05/2011	48			1				
Power Networks Research Academy	EPSRC	10/2008	79							1
Preventing wide-area blackouts through adaptive islanding of transmission networks	EPSRC	01/2010	48		1					
MOLTEN: Mathematics Of Large Technological Evolving Networks	EPSRC	01/2011	24							1
INTEGRATED ASSESSMENT OF QUALITY OF SUPPLY IN FUTURE ELECTRICITY NETWORKS	EPSRC	04/2010	34		1	1				
FreCon	EPSRC	11/2009	36		1	1				
Enhanced Exploitation of Smart Metering Using Novel High Performance Computing - Part 2	EPSRC	04/2010	42		1	1				
HYDRA	EPSRC	04/2010	24							1
USE-IT: Using Smart Energy through Intelligent Technology	EPSRC	04/2010	36	1						
Multiscale Modelling to maximise Demand Side Management	EPSRC	09/2010	36		1					
Novel Asynchronous Algorithms and Software for Large Sparse Systems	UKERC	10/2010	42							1

Informing Energy Choices Using Ubiquitous Sensing	EPSRC	08/2010	24	1						
Industrial Doctorate Centre: Technologies for Sustainable Built Environments	EPSRC	10/2009	102	1						
Energy Efficient Cities	EPSRC	09/2008	60		1					
Capacity to Customers	LCNF				1					
Customer Led Network Revolution	LCNF	01/2011	48		1					
Low Carbon London	LCNF		42		1			1		
Low Carbon Hub	LCNF		48		1	1				
Low Voltage Network Templates for a low carbon future	LCNF		27		1					
Hook Norton Low Carbon Community Smart Grid					1	1				
ADDRESS: Active Distribution network with full integration of Demand and distributed energy RESourceS Call: FP7-ENERGY Period: 2008-2012	FP7-ENERGY	06/2008	48		1			1	1	
CER Irish Trials				1		1		1		
			Totals:	35	35	30	18	13	6	7