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RESEARCH PAPER

Smart metering: what potential for householder engagement?

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The argument for the implementation of 'smart' metering, which is an elastic term, varies according to circumstance and place. In some countries, the business case for establishing an advanced metering infrastructure (AMI) relies in part on improving consumption feedback to customers and assisting in the transition to lower-impact energy systems. There is an expectation that AMI will lead to reductions in both the demand and the cost to serve customers through improved communication, but little evidence exists to show overall demand reduction. To what extent might smart meters improve the prospects for customer engagement? To assess this question, end-user perceptions and practices must be considered along with metering hardware and economics. Using the theory of affordances, qualitative research is examined to understand how householders have used consumption feedback, with and without smart meters. Although AMI offers possibilities for household energy management and customer–utility relations, there is little evidence to suggest it will automatically achieve a significant reduction in energy demand. For that, there has to be a determined focus on overall demand reduction (rather than on peak electricity demand reduction), on designing customer interfaces for ease of understanding, and on guiding occupants towards appropriate action. Appropriate forms of interface, feedback, narrative, and support will be needed to reach diverse populations.

Keywords: affordances, behaviour, energy demand, energy management, feedback, households, housing, human agency, smart metering

Les arguments en faveur de la mise en œuvre d'un comptage «intelligent», qui est un terme souple, varient en fonction des circonstances et du pays concerné. Dans certains pays, le business case pour mettre en place une infrastructure de comptage avancée (AMI) s'appuie en partie sur une amélioration du retour d'information fourni aux clients sur leur consommation, et sur l'aide apportée pour passer à des systèmes énergétiques présentant un impact moindre. Il est attendu d'une AMI qu'elle conduise à la fois à une réduction de la demande et à une réduction du coût de desserte des clients grâce à des améliorations en terme de communication, mais il existe peu de données probantes à l'appui d'une réduction globale de la demande. Dans quelle mesure des compteurs intelligents pourraient-ils améliorer les chances de voir le client s'impliquer? Afin d'évaluer cette question, il est nécessaire d'examiner les perceptions et les pratiques des utilisateurs finaux en même temps que le matériel de comptage et les aspects économiques. En utilisant la théorie des affordances, l'étude qualitative est examinée de façon à comprendre comment les occupants ont utilisé le retour d'information sur leur consommation, avec et sans compteurs intelligents. Bien qu'une AMI offre des possibilités en matière de gestion énergétique des ménages et de relations client-fournisseur d'énergie, il y a peu de données probantes permettant de suggérer que cela assurera automatiquement une réduction sensible de la demande énergétique. Pour ce faire, il importe de mettre l'accent sur une réduction globale de la demande (plutôt que sur une réduction des pics de consommation électrique), sur la conception d'interfaces client faciles à comprendre et sur la fourniture de conseils aux occupants pour qu'ils prennent les mesures appropriées. Il sera nécessaire de disposer d'interfaces, d'un retour d'information, de descriptifs et d'une assistance aux formes adaptées pour pouvoir toucher des populations diverses.

Mots clés: affordances, comportement, demande énergétique, gestion énergétique, retour d'information, ménages, logement, *human agency*, comptage intelligent

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Introduction

Smart metering, though first proposed in the 1970s, has only come into full view during the past decade. Commercial interest has now reached the point at which present and future investment in smart metering in the European Union has been estimated at €51 billion, with potential financial benefits ranging from €14 billion to €67 billion (Faruqui *et al.*, 2009a). Smart metering is a relatively new addition to the energy policy toolbox, and the terminology is still developing. It is worth taking time to look at some of the components of advanced metering infrastructure (AMI), and to examine how these relate to household energy management, the need to reduce overall or peak demand, and the adoption of domestic low- and zero-carbon technologies. In particular, this paper deals with questions of customer engagement with some of the technical and management systems that are made possible by AMI. Is smart metering capable of supporting the types of relationship and practice that are likely to lead to lower-impact energy use?

This is approached in the following sequence: the concept of affordances is introduced and briefly discussed, then definitions relating to smart metering are considered. An outline of the European and United Kingdom policy contexts for smart metering follows; a look will then be made at the uses of energy feedback to consumers. An account of some recent qualitative research on customer experiences of using feedback leads into the summary and conclusions.

Affordances

The idea of affordances was introduced by the psychologist J. J. Gibson to convey the possibilities for action in one's surroundings (Gibson, 1977). Affordances were defined as the 'action possibilities' latent in the environment. They are measurable and exist independently of whether they are recognized by an organism or actor; but at the same time they exist *in relation to the abilities of an actor*. A ball of wool presents different affordances to a cat, a child or an adult, for example. The term has been described as 'an attempt to put meaning back into the world, within a relational ontology' – interpreting things as they are both perceived and used – at a time when the dualisms between humanity and 'nature', quantity and quality, were particularly pronounced in the industrialized world (Costall, 1995, p. 477).

The concept of affordances thus brings together physical properties, agency, and meaning. Affordances exist in the 'natural' world, but are also designed into one's surroundings. In terms of daily practice, 'meaning' is not an optional extra for a well-designed affordance. People *need* to know what red buttons, arrow keys or dialling tones mean in order to go about their business safely and effectively: perceived affordance can be at least as important as actual (physical) affordance (Norman, 1999).

Introducing this concept to a consideration of a new technological application, smart metering, is useful not only because it puts the energy user close to the centre of the discussion, but also because it sites the energy user *in relation to* technology, and in relation to the designers of a smart metering system. In this way, it sheds some light on the possibilities for householder engagement with smart meters. Before considering wider issues related to metering, the idea of affordances provides a useful way of contemplating possible interactions between householders and their artefacts in future, 'smarter' homes. Figure 1 is representative of many diagrams showing possible energy configurations in homes in the not-too-far-distant future.

Figure 1 illustrates a number of relatively new affordances, some of which are already in use. The people living in this house can opt to use a 'smart thermostat' that can communicate with the grid, with the option of remote management by network operators or third parties in order to balance supply and demand at any instant. They may control their energy usage remotely themselves, too – switching the central heating or the cooker on or off from work, or from the car. The real-time pricing signals from the home's smart meter will 'create increased options' for customers, who can choose tariffs that suit their daily consumption patterns, and may decide to alter their normal practices and behaviours in order to avoid high spot electricity prices. In this scenario, the home has become a site where electricity is generated as well as consumed (through solar photovoltaic panels on the roof). It has also become a means of managing the electricity system by a combination of the utility, the customer, and a set of appliances that communicate with each other and with the distribution network. The car has changed in nature, too, having become more than a means of transport: it stores and releases electricity on demand when plugged into and controlled through the grid.

What might these affordances mean in practice, and for whom? In spite of the references to personal needs and personal choice, most are presented essentially from the point of view of the controller of the electricity grid. As Costall (1995) points out, affordances do not *cause* behaviour, but they can constrain or control it; and they can also enable it. In what ways is behaviour likely to be enabled or constrained in a 'smart home' scenario, where there will be new, emergent effects, and what are the potential outcomes? The main offer to the householder appears to be automation of some functions and the prospect of some form of time-varying electricity pricing, plus a degree

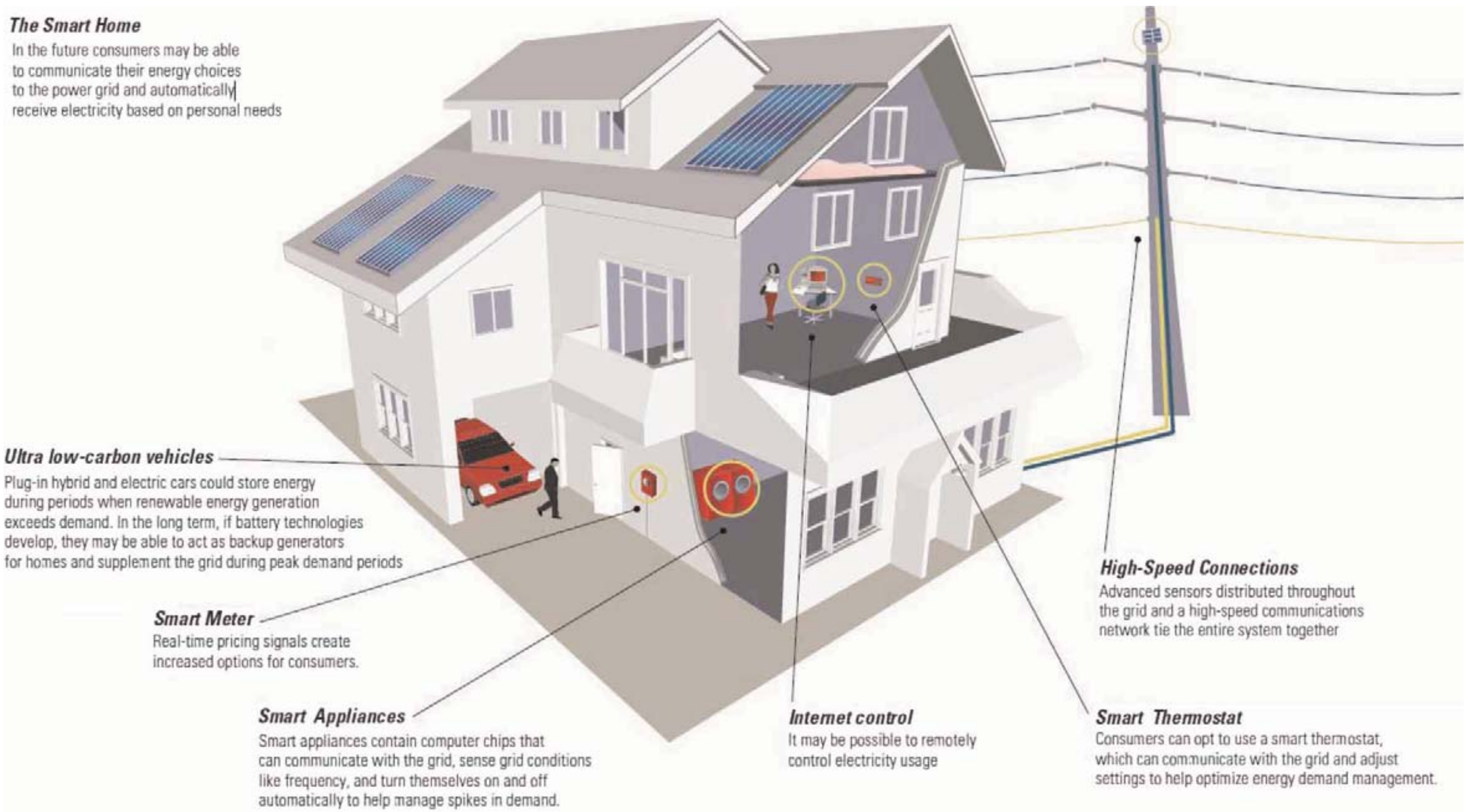

Figure 1 A 'smart home' complete with an electric vehicle, smart appliances and thermostat, and remote controls. Source: Xcel energy, used by the UK Department of Energy and Climate Change (DECC) at a public briefing, 16 December 2009

of remote control via the Internet. This sort of control would be attractive to a segment of the population, but it could alienate others and has not, to date, shown any substantial evidence of reducing demand. Programmed heating controls do not necessarily do what they are designed to do: result in lower maximum temperatures or shorter heating periods (*e.g.* Williams *et al.*, 1985; Shipworth *et al.*, 2010). Taking control away from the customer cannot be relied upon to improve the situation: it may actually entrench and legitimize high-demand practices, disengaging customers from any need to consider and question them (Strengers, 2008).

Other assumptions are called into question once one looks at the scenario in a relational way, in terms of what it affords to different actors in different situations. For example, the electric car would be 'ultra-low carbon' only if supplied from an ultra-low carbon-generating mix, something that is not assured. It would not be worth installing the 'smart' technology into a low-consuming building in either financial or energy terms: it would consume more electricity than it would 'save'. The picture does not indicate any interface other than the Internet to inform the customer about the scale and timing of electrical usage – there is no obvious, accessible source of feedback for guidance. There is no mention of gas, either – something that will account for a large proportion of emissions from housing in the near- and mid-term. And how much will the average customer want 'increased options' for paying for the electricity supply according to time of usage? Such options will need very careful design if they are to appeal to the customer as much as they appeal to the utility. There are elements in this 'smart home' that *could* reduce environmental impact; but reduction is not guaranteed, especially if consumption is normally low.

This picture only tells part of a wider story, of course. There are other affordances to 'smart' technology that can offer benefits to different actors in an energy system. For example, the use of new technology could be widely welcomed if it led to any of the following: reduced fraud and theft; elimination of the cost of employing meter readers and the inconvenience to some customers of waiting for them to call;[1] an end to the stigma and additional cost attached to prepayment; reductions in peak demand and avoided investment in new capacity; a lower environmental impact from avoiding an inefficient or high-carbon marginal generating plant; and improvements in the efficiency of the market. (These benefits were identified in a review by Owen and Ward (2006). Some likely benefits from variants of 'smart metering' with their particular affordances are also summarized by Darby (2009).)

Here, though, the main interest is in a particular element of 'smart' technology: the metering arrangements. Can these engage the householder more successfully than they have done to date and, if so, how? Where does the agency of householders fit into the picture? What can they do, and learn from, in a home with smart metering? The theory of affordances points to the conclusion that a socio-technical innovation such as smart metering is likely to involve a great deal more than automation and fine control. Much of its significance can be described in relational terms – in terms of how people and things interact with other people and things, and to what ends.

Smart metering – technologies and narratives

A discussion of smart metering is often accompanied by a good deal of confusion about purpose and functionality, so it is necessary to start with definitions. To begin with a basic definition, 'smart' meters are primarily 'non-dumb', *i.e.* they communicate electronically, as:

> advanced meters that identify consumption in more detail than conventional meters and communicate via a network back to the utility for monitoring and billing purposes.
>
> (Climate Group, 2008, p. 85)

It is not always necessary to replace a meter in order to achieve smartness: a 'dumb' meter can be 'smarted' by retrofitting it with communications capability, and this is a less expensive option, for comparable specification. (Dimitropoulos (2007) gives a useful appraisal of costs and benefits of the equipment and rollout options open to UK utilities.)

Taking the definition a little further, the literature shows general agreement that a fully smart meter is one that can (1) measure and store data at specified intervals and (2) act as a node for two-way communications between supplier and consumer and automated meter management (AMM). This allows for a radical change in customer–utility relations, with the possibility of remote disconnection and reconnection, remote change of tariff, and remote change in 'contractual power' (the peak electrical demand allowed for an individual customer, a familiar concept in Italy and France, for example).

Simpler versions of communicating meters, usually referred to as 'advanced' rather than 'smart', have one-way communications only, from customer to utility. These are referred to as automated meter reading (AMR) meters, and have been used by industrial and commercial customers for many years, typically measuring consumption at half-hourly intervals for electricity, hourly for gas (Owen and Ward, 2006). They ensure accurate billing, make supplier switching more straightforward, and detect fraud more easily than standard credit meters.

The term 'advanced metering infrastructure' (AMI) refers to the *system* of meters and associated communications. AMI offers accurate, fraud-resistant measurement (*e.g.* it tells the supplier when usage is suspiciously high or low, or when there is evidence of tampering), and improved information flows to enable demand response – the management of demand in relation to prevailing supply conditions (Batlle and Rodilla, 2008). It allows for communication hubs that can be used for the remote control of electrical appliances, in order to optimize network operation and the use of intermittent renewable supply. And it offers the prospect of integrated metering and recording for consumption and on-site generation. The most ambitious form of AMI, the 'smart grid', is planned to carry out load control at high resolution (the remote control of individual appliances from second to second), in order to cope with fluctuations in supply as well as demand. This is expected to become increasingly necessary as more intermittent renewable generation comes on stream (for an overview of the scope of smart grids, see European Commission, 2006a). Smart grids are still in the early pilot stage.

A further definitional twist, but an essential one for this paper, comes from the separate development of electronic consumption displays, or in-home displays. These are widely (but misleadingly) known as 'smart meters'. Most display electricity usage, with a few also showing gas and water consumption. While many models are designed to operate with conventional meters, by sending signals to a display panel from a transponder attached to the meter tail, some recent models can operate with smart meters, showing accurate data that coincide with billing information.

The research literature shows that in-home displays give interested users enough new feedback information (on real-time and historic usage) to help them understand and manage their electricity better, achieving savings in the range of 5–15% (Darby, 2006a) or, in a more recent review, 7% on average for customers buying on credit and twice that when combined with prepayment (Faruqui *et al.*, 2009b). There is also some evidence that displays have an enduring impact even if only used for short periods, through changed habits and investment in efficiency measures (Darby, 2006a; Rossini, 2009). The range of findings reflects factors such as variations in equipment used, social and climatic circumstances, regulatory regimes and fuel pricing, and the conduct of trials. How well such displays perform in a population will depend on how successfully they engage the interest of consumers, and maintain engagement: overall impact is a product of individual savings from increased awareness and the proportion of customers who decide to use the new interface.

Table 1 indicates schematically what some terms and functions might mean from a consumer standpoint. Vasconcelos (2008) gives a useful glossary of terms in the context of European policy objectives.

AMI can be used to link meters for gas, heat, electricity and water, transmitting data to utilities, end-users and/or third parties (Marvin *et al.*, 1999). Developments in multi-utility metering and information have been somewhat slow, however, reflecting the difficulty of mobilizing disparate industries for demand management, particularly when they are operating in liberalized markets. Yet a multi-utility approach, focusing

Table 1 Potential smart metering outcomes from a consumer standpoint

	Customer display	Advanced metering/AMR	Smart metering/AMM (with AMI)	Smart grid
An end to estimated bills; no need to wait in for a meter reader to call		×	×	×
Real-time and/or historic and comparative consumption feedback to the customer	×	Possible	Possible	Possible
Detailed consumption feedback to the utility		×	×	×
Fraud reduction		×	×	×
Remote connection/disconnection			×	×
Remote tariff switching			×	×
Easier supplier switching			×	×
Integration of microgeneration		Possible	×	×
Remote control of appliances for load management			Possible	×
Connections with home security systems, etc.	Possible	Possible	Possible	Possible

Notes: This is schematic only.
AMM, automated meter management; AMR, automated meter reading.

Table 2 Motives and contexts for smart metering in six different countries

	Principal motives	Smart metering status	Regulation	Comments
California	Load management/ peak reduction	In progress for electricity, with gas 'piggybacking'	Large local monopolies, vertical integration	Some success with peak reduction; a low but a growing interest in demand reduction; some strong customer resistance
Italy	Fraud reduction; contractual power control/load limiting	Rollout almost complete (electricity)	Slight competition, with ENEL dominant	Payback time of less than five years is claimed; no customer displays as yet
Malta	Fraud reduction, water conservation	Rollout to begin soon	Monopoly	Demand reduction low down on the list of priorities; no customer displays
Netherlands	Demand reduction, load management	Mandatory rollout halted; terms being renegotiated	Liberalized; networks own meters	Legal challenge on data privacy halted the rollout; customer displays being developed as part of the offer
Ontario, Canada	Load management	Rollout complete; time-of-use pricing now under way	Many local monopolies	Some successes with demand reduction from trials with in-home displays, but they are not rolled out with the smart meters
Sweden	Accurate billing	Rollout complete	Liberalized; networks' own meters	Some web-based feedback to customers; very few displays

ENEL, Ente Nationale per l'Energia eLettrica.

on overall resource management, is arguably more urgent than a network-management focus.

These aspects are discussed in more detail below, but the main point to stress here is that narratives about smart metering can vary considerably according to technology, context and priorities. Table 2 summarizes the drivers behind the rollout of smart metering in six different countries/legislatures, and shows how energy efficiency and demand reduction are only a part of the story. It gives an idea of the diversity that is already evident, and indicates how cost–benefit calculations for AMI are likely to vary widely with geography. For example, in parts of the world with high and infrequent peaks in electricity demand, there is a clear economic case for peak reduction and for using smart meters in connection with time-of-use pricing and/or direct load control. Elsewhere, fraud and theft pose a major threat to large-scale utilities and smart metering offers a way of reducing this – there are widespread reports of the Italian rollout of electricity smart meters paying for itself within five years, primarily through fraud reduction.[2] The need for some regions to accommodate an increasing proportion of intermittent supply also calls for flexible matching of supply with demand, in a way that cannot be achieved with conventional metering.

Smart metering in Europe

In the European Union, a link between the metering system and better energy management was established in Article 13 of the 2006 Energy Service Directive:

> Member States shall ensure that, in so far as it is technically possible, financially reasonable and proportionate in relation to the potential energy savings, final customers … are provided with competitively priced individual meters that accurately reflect actual energy consumption and that provide information on actual time of use …
>
> … Billing on the basis of actual consumption shall be performed frequently enough to enable customers to regulate their own energy consumption.
>
> Member States shall ensure that, where appropriate, the following information is made available to final customers in clear and understandable terms … in or with their bills …:
>
> Current actual prices and actual consumption of energy;
>
> Comparisons of the final customer's current energy consumption with consumption for the same period in the previous year, preferably in graphical form;
>
> Wherever possible and useful, comparisons with an average normalised or benchmarked user of energy of the same user category …
>
> (European Commission, 2006b)

There is an explicit intention to improve customers' ability to manage energy and to encourage time-of-use pricing. Smart meters are not mentioned as such, although automated reading of interval meters (at least) is implied by the requirement for frequent, accurate billing and for information on time of use.

Three years later, European Union policy language had developed into the following, in Article 3 of a Directive 2009/72:

> ... customers are entitled to receive all relevant consumption data ... to promote energy efficiency, Member States shall strongly recommend that electricity undertakings optimise the use of electricity, for example by providing energy management services, developing innovative pricing formulas, *introducing intelligent metering systems or smart grids*, where appropriate ....
> (European Commission, 2009)

In the Annex of Measures for Consumer Protection, Directive 2009/72 states that this Article is to ensure that customers:

> have *at their disposal* their consumption data, and shall be able to, by explicit agreement and free of charge, give any registered supply undertaking access to its metering data. The party responsible for data management shall be obliged to give those data to the undertaking. Member States shall define a format for the data and a procedure for suppliers and consumers to have access to the data ...

and that they are:

> properly informed of actual electricity consumption and costs *frequently enough to enable them to regulate their own electricity consumption*. That information shall be given by using a sufficient time frame, which takes account of the capability of customers' metering equipment and the electricity product in question. Due account shall be taken of the cost-efficiency of such measures. No additional costs shall be charged to the consumer for that service.
> (European Commission, 2009)

Intelligent metering systems are now specifically recommended; there is a statement of the right of the consumer to have his/her own data 'at disposal'; and the need for customers to be able to regulate their consumption is restated.

Metering at national level: interpretations and implementation in the UK

In countries with relatively smooth electrical demand and lower levels of fraud, a business case for smart metering has to incorporate the potential value of additional customer services and environmental benefits. In the UK, this has included the potential to improve direct consumption feedback to customers, along with more accurate billing (Darby, 2008). It is argued that this will bring help down overall demand through improved energy management, with benefits to society in the shape of lower environmental impact, lower energy bills, and greater energy security. But in order for this to happen, there has to be an effective means of communication with the customer. Table 3 gives the functionality that is anticipated for electricity and gas smart meters for the UK, which includes the ability to provide real-time information to an in-home display (Department of Energy and Climate Change (DECC), 2009b). It also includes the capacity to communicate with microgeneration measurement devices.

The UK and Irish governments have taken the idea of using smart meters as a tool for carbon reductions further than most, and both have decided to proceed with national rollouts of AMI, although many elements of equipment, procedures, and regulation remain to be decided. Trials of various meters and feedback interventions are under way at the time of writing (2010) in both countries (Ofgem, 2010; Commission for Energy Regulation (CER), 2009), with the aim of testing technologies and learning more about the impacts on behaviour of a range of feedback modes.

In operational terms, the introduction of smart meters is a huge undertaking: for the UK, according to a recent presentation by the Department of Energy and Climate Change (DECC), it is:

> arguably the biggest energy industry change programme since the changeover to North Sea gas.[3]

If all goes ahead as planned, both gas and electricity will be smart metered by the end of 2020. In addition to testing, development, and investment in measurement and communication technologies, there is much regulatory and legal work to be done ahead of implementation.

In its recent response to the UK government consultation on electricity and gas smart metering, DECC stresses both customer service and emissions reduction, stating that:

> Smart meters will pave the way for a transformation in the way that energy is supplied and consumed, contributing to our goals of energy security and carbon reduction. They will provide energy consumers with real-time information about their energy use, enabling them to monitor and reduce their energy consumption and carbon emissions. Smart meters will support improved energy efficiency advice and facilitate smoother, faster switching between suppliers. And they are an important step towards the future development

Table 3 Functionality expected from a smart meter in the UK

Function	Electricity	Gas
Remote provision of accurate reads/information for defined time periods Delivery of information to customers, suppliers and other designated market organizations	√	√
Two-way communications to the meter system Communications between the meter and energy supplier or other designated market organizations Upload and download data through a link to the wider area network, transfer data at defined periods, remote configuration and diagnostics, software and firmware changes	√	√
Home area network based on open standards and protocols Provide 'real-time' information to an in-home display, other devices to link to the meter system	√	√
Support for a range of time-of-use tariffs Multiple registers within the meter for billing purposes	√	√
Load management capability to deliver demand-side management Ability to control electricity load remotely for more sophisticated control of devices in the home	√	
Remote disablement and enablement of supply That will support remote switching between credit and pre-payment	√	?
Exported electricity measurement Measure net export	√	
Capacity to communicate with a measurement device within a microgenerator Receive, store, and communicate total generation for billing	√	

Source: Department of Energy and Climate Change (DECC) (2009b).

> of a smarter grid delivering improved network efficiency and responsiveness, which will in turn help facilitate the introduction and increased use of renewable energy and ultra low carbon vehicles (electric and plug-in hybrids).
>
> (DECC, 2009a)

Note that the smart meter is defined here not simply as a piece of equipment to manage supply and collect payment, but as part of a much wider system for communication, awareness-building and energy management. This is an absolutely crucial issue: there are growing reports of backlashes against smart meters from customers in the Netherlands, California, Texas and elsewhere, for reasons ranging from perceived invasion of privacy to perceived increases in bills due to the meters, and resentment at having to pay for an unwelcome new piece of equipment. Yet, installations in Italy and Scandinavia have been uncontroversial. How much is this due to the relatively modest intentions behind rollouts there, and how much to high levels of trust between the parties, or other reasons? It is beyond the scope of this paper to go into detail, but the point is made that it is risky for utilities and their regulators to adopt a 'fit-and-forget' attitude to any new technology in the belief that it will, unsupported, achieve their goals and be acceptable to consumers.[4] At the time of writing, the UK regulator is attempting to address the social aspects of a smart metering rollout by developing the ground rules with the help of stakeholder workshops and a Consumer Advisory Group.[5]

The UK is an interesting site for examining the potential of smart meters to engage energy users in the operation of energy systems. Consumers often have low levels of understanding of their energy bills, around one-third of which are likely to be based on estimates rather than readings (Logica, 2007; energywatch, 2007). They also own increasing numbers of appliances, many without any obvious power rating or energy label, which are 'managed' in a range of different ways (for an overview of appliance types and the user interactions that they afford, see Wood and Newborough, 2007). These have inexorably pushed up household electricity consumption over the past few decades. The 2009 *Digest of United Kingdom Energy Statistics (DUKES)* shows a levelling-off between 2005 and 2008, but that is hardly encouraging, given the confounding impact of recession (DECC, 2009c). The trend for residential gas usage is only slightly more encouraging, but as yet there are not many signs that householders are confident about controlling and reducing their consumption, either in terms of purchases of equipment, maintenance of buildings or day-to-day usage. Smart metering could allow them to come in from the periphery of energy systems as active investors and managers rather than more or less fatalistic bill-payers; or it could pave the way for more passive cooperation with energy suppliers or third parties, by making their homes into sites for remote control of usage. Or there could be some combination of these approaches. The usability and intelligibility of specific pieces of equipment are relevant here.

Feedback, learning and energy management

In order to move from the periphery of an energy system to full 'participant' status, a measure of learning is needed. That is, the acquisition and use of practical knowledge, both tacit and explicit. Some of this can be encouraged through educational campaigns, advertisements, advisory services and news media; but much of it is likely to come from day-by-day experiential learning that is 'situated' and social (Lave and Wenger, 1991).

The potential of smart metering for customer engagement will be related to its ability to encourage and provide for day-to-day use by householders, and the most likely mechanism is through improved feedback from accurate, frequent billing and/or easily available information on consumption (or generation) in real-time and over specified periods.

Any future AMI will be set up to provide increased information flows, with a view to improving network management. As discussed above, it may also be able to provide useful information to customers that can augment what they already know from observation and experience of their homes, appliances and controls.

There is a clear need for improving householders' working knowledge (as opposed to 'information'). As many studies have shown, knowledge of energy use in buildings is often extremely patchy, while usage is highly variable and strongly connected with routines and practices that have little to do with knowledge (Gram-Hansen, 2010; Guerra-Santin and Itard, 2010). The awareness-raising impact of domestic energy consumption feedback has been documented in relation to learning and behaviour change in a number of reviews (*e.g.* Darby 2006a; Wilson and Dowlatabadi, 2007; Fischer, 2008; Faruqui *et al.*, 2009b). In almost all cases, though, this impact has been achieved *without* smart meters. The feedback came from careful, frequent meter-reading by the householder; or through the efforts of researchers who informed householders about their consumption and how it related to benchmarks; or, through a more frequent and informative bill, or (most recently) an electronic display. The important thing was that the householder had *new, actionable information* on consumption that could be clearly understood, with access to relevant comparators, whether these were historic consumption records, comparisons with similar households or a chosen target, or comparisons between end-uses.

Some customers will have more power to make changes than others because they have more resources at their disposal and/or because they are allowed to do more. As a recent IBM report commented, a broad range in the quantity, direction, and quality of information flows in an electricity system is possible:

> At the lower end of the technology spectrum, power generation is centralised, and information and energy flow in only one direction. At the upper end, smart metering, enhanced network sensing and communications, and self-generation technologies create a dynamic consumption/generation network where information and energy flow in both directions. In terms of consumer control, one extreme represents a completely 'utility-determined' relationship in which consumers have very little say. The opposite extreme is a 'customer-driven' experience, with consumers controlling major aspects of how they meet their energy needs.
>
> (Valocchi *et al.*, 2007, p. 13)

Of course, customers do not necessarily 'drive' a relationship simply because information flows in two directions between themselves and a utility. Even if they gain influence in the customer–utility relationship, they do not necessarily use it to reduce their demand. Valocchi *et al.* divide customers into four categories according to disposition: the 'energy epicures' who consume heavily; the passive customers who take little or no interest in managing their usage; the 'stalwarts' who are careful and innovative; and the frugal customers who are obliged to keep their costs down. The numbers in the first two groups are slightly more than in the second two, and the challenge is to shift people in the direction of becoming an 'energy stalwart'.

If the aim is to make the customer central to a smart metering rollout (for an example, see DECC, 2009a, 2009b), a determined effort has to be made to identify affordances for customer engagement – physical and relational characteristics of a system – and include them in the specifications. The literature cited in this section gives some pointers, and the following section adds to these by considering a sample of qualitative research into attempts to engage householders with various forms of energy feedback information.

Qualitative research on householder use of consumption feedback

As noted above, most of what is known about the uses of consumption feedback was learned using old-style, 'dumb' metering. Much of this has continuing relevance, though. Fischer (2008) summarizes what is known about the qualities of 'successful' feedback, acknowledging gaps in the research literature. Ideally, such feedback includes at least two of the following characteristics:

- multiple options for the user to choose from
- an interactive element
- frequency more often than monthly (continuously, daily load curves, or immediately after the action [of switching on or off])
- detailed, appliance-specific breakdown of usage, and
- comparisons with previous periods

Qualitative work on feedback gives some more clues, illustrating something of the range of meanings of feedback to energy users. Three types of feedback usage are reviewed below: 'standard', unenhanced feedback from the energy bill and meter, illustrated with some interview material from a study carried out in Oxfordshire; feedback from an in-home display; and web applications.

Interpretation of the bill and meter: some customer experiences

In their innovative study of 'folk' energy analysis, Kempton and Layne (1994) found a surprisingly high level of interest and data collection among the 56 Midwestern US householders they interviewed. They noted that individuals were limited by their lack of ability to analyse the data in terms of weather correction, price correction, comparisons, and meaningful units. The kilowatt-hour (kWh) was seen as largely irrelevant by comparison with cost, although over time it is a far more reliable unit of comparison. The authors pointed out that the bill not only told them how much they owe the utility, but also it helped to check that no unusual consumption was occurring, and to evaluate the effectiveness of any energy conservation interventions.

The present author found examples of all these in interviews with householders in an Oxfordshire village in the course of a study of social learning and responses to energy advice. This sprang from an interest in assessing how energy-related knowledge was constructed over time. Twenty semi-structured interviews were conducted with residents who had taken part in a survey of the entire village, and were selected as representing differing levels of energy awareness and engagement (for a report on the study, see Darby, 2006b). When asked if she had ever needed to use the bills that she kept in a dispute with her supplier, one respondent replied:

> I have, actually. . . . I used to check the meter – still do, specially when it's estimated, to make sure that we're not building up a lot [of debt]. Yes, they read it completely incorrectly and sent somebody back who swore it was right, but I knew it was wrong. And they said we didn't owe them much at all. And I knew that next time they came it would all be there, and it was.
>
> [And you pay quarterly rather than by direct debit?]
>
> Yes.
>
> [Any particular reason?]
>
> I like, I suppose, to know how much I use every quarter and to check that it doesn't change that much. Specially when we have, like, the new heater now and we're using the convector in the evening. I shall be interested to see how much that changes things.

Another interviewee commented that:

> My consumption over the past quarter is actually 50% higher than they estimate it to be. But then it has been winter and I know that when they estimate they take your average for the year. . . . I pay whatever they want, really. . . . [I] probably first started thinking about it when I was first at university – the first time we were actually paying our own bills. So you quickly learnt how much it cost to actually have a bath . . . you actually watched the meter go round and that kind of thing! You'd be very conscious if the immersion heater was left on . . ..

The affordance of both meter and bill to the customer can change according to design and practice, though not always in a helpful direction. Direct debit, with payments spread evenly over the year, can divorce the customer from the realities of consumption. Another respondent commented that:

> . . . well, I suppose it is reading the meter but it doesn't have the same concept it used to have [before paying by direct debit]. Where a bill followed a fortnight later saying, You owe us. It doesn't happen . . . it's judged over the year, obviously, because as the summer progresses you turn the heating off to a point where you don't have any heating on at all in the house, other than hot water. So then they balance the high energy by the low energy and take a middle ground.

On the other hand, bills can be developed to give frequent and regular 'reality checks'. A classic study of informative billing in Stavanger, Norway, concluded that the main single influence behind observed reductions in usage was the increased frequency with which customers received an accurate bill: the change from an annual bill based on a meter reading to an accurate bill every 60 days allowed customers to connect the quantities used with any changes in routine or practice that they remembered over the previous few week (Wilhite and Ling, 1995). Later work showed an enthusiasm for normative/comparative feedback among householders, and for information on how consumption was divided among end-uses; it also showed increased utility interest in providing this to customers, provided the cost was not prohibitive, now that the electricity market was being opened up to competition and improved feedback had the potential to increase customer loyalty to the supplier (Wilhite *et al.*, 1999).

Findings such as these helped prepare the way for considering what could be done with more sophisticated information management, allied with psychological insight. (Schultz *et al.* (2007) give a well-known example of developing reliable, trusted comparative feedback.) OPOWER, a large-scale, low-technology system for billing feedback in the United States, which compares household usage with that of members of matched comparison group, 'all neighbours', and 'efficient neighbours', has shown reductions in electricity usage for 35 000 participants against a control group, rising from 2% to 3% over the first two years of operation. The cost to the customer is only US$10, and roughly 85% of customers participate in the scheme. OPOWER does not require smart metering, though it does require regular meter readings. Customers with monthly readings saved more than those with quarterly readings (Klos, 2009).

Interpreting an in-home display

In-home energy displays, which began to appear on the market around 2005, represent a step forward from the bill in terms of immediacy and interactivity. Almost all displays show electrical consumption in real time.[6] The 'second generation' of displays can also give an indication of historical usage; and 'third-generation' displays, allied with smart meters, can give a range of highly accurate information on both current and former usage.

The affordances of displays vary according to the characteristics of the device and the user. As with heating controls, there is evidence that some displays are designed without much thought as to their usability by non-engineers. Allen and Janda (2006) carried out a small-scale test of a simple real-time electricity display in Ohio and found that half of the participating householders had not been prepared to go beyond the default screen of the display, which showed them their current demand in kilowatts (kW) and their (extrapolated) cost per hour. This screen did not give any clues as to what they should do next; and when they did come to look at other features of the monitor, they were somewhat confused by them. What might appear to be additional affordances can thus stand in the way of understanding.

Kidd and Williams (2008), in an in-depth study of ten Welsh householders, pointed out further challenges for designers as well as positive outcomes. For example, 'understanding consumption is a tricky cognitive problem' for many people, involving the concept of power multiplied by time. The display used for this study had the useful primary function of drawing attention to energy use and illustrating the relative power of different end-uses; but the 'drama' of seeing real-time consumption figure jump up and down can distract householders from identifying those appliances that contribute most to usage over time. There is a distinct problem with real-time monitors that show the size of instantaneous demand and then extrapolate it to give wildly differing costs within the space of a few minutes, according to what is switched on and functioning at a given moment. What is the user to believe?

As part of their response to the government consultation exercise on smart metering in 2009, the Energy Saving Trust commissioned a qualitative study from the Centre for Sustainable Energy to contribute to a functional specification for home electricity displays. Five focus groups were recruited and asked to design their own display. They then took home one of the displays on the market at the time, used it for a week, kept a diary of their experience, and reconvened to redesign their display. Participants reported that they had been motivated by the displays to perform a range of actions that could be summarized as:

- turning off
- using less
- using more carefully
- improving performance, and
- replacement or use of alternative appliances

There was general enthusiasm for what the participants had learned in the course of their week with the displays, even though most of them had been well below what they saw as ideal specification. The results of the study show variability in individual experiences, as might be expected, and some generic issues. But in spite of these, there was a surprising degree of consensus about desirable information and functionality, summarized in Table 4.

Only one of the displays on the market at the time came close to meeting this functional specification,[7] having an analogue indicator.

Recent small-scale qualitative trials of five in-home displays in 95 Nevada households found that householders valued the easily-accessible cost and usage information along with the sense of control that it

Table 4 Householder specifications for information and functionality of an in-home electricity display

The default display should include:	• *Clear analogue indicator of the current rate of consumption* • *Current rate of consumption as a rate of spend (£/day) (numeric)* • *Cumulative daily spend (£) (numeric)*
The display should offer these options through interaction (by pressing a single button)	• *Spend in the last seven days, day by day* • *Spend in the last complete week* • *Spend in the last complete month* • *Spend in the last complete quarter*
Historic periods should match the utility's billing periods, so that the display is consistent with household bills	
There should be the option (by pressing a single button) of switching units from money to power and energy, i.e. from £ per day and £ to kW and kWh	
The display should be mains powered but have an internal battery to enable mobility in the home	
Target setting should be considered as part of the core specification, but more evidence is needed of the value of such an option over a longer period of use. It is not clear whether this extra functionality warrants the cost of increased complexity	
If interaction with the display is not possible, this should be the default content:	• *A clear analogue indicator of current rate of consumption* • *Current rate of consumption as a rate of spend (£/day) (numeric)* • *Current rate of consumption (kW) (numeric)* • *Cumulative daily spend (£) (numeric)*

Source: Anderson and White (2009), p. 3.

gave them, and thought that utilities should make home displays widely available. Two-thirds of participants saved electricity while using their displays and they were, on average, prepared to spend more time than the non-savers trying to make the devices work for them. Around one-fifth of the sample, though, 'were not served well by mere distribution and installation of devices, without further customer support' (Boice, 2009, p. 8).

The stories of those who are not interested in their displays, or who cannot put them to use for energy management,[8] add an important dimension to the unfolding story of smart metering. They highlight the need for simple, clear customer interfaces, but also for an approach that recognizes the limitations of AMI technologies. There are the customers who do not care about what they are consuming, and who may simply use smart-meter-generated feedback to confirm that nothing out of the ordinary is happening (Ersson and Pyrko, 2009). And there are those who feel that they have already reached the limit of what they can do to reduce their consumption. Hargreaves (2010), who found generally positive responses to a particular type of in-home displays, but also frustration and anxiety, emphasizes the importance of recognizing that displays are used in a social context (normally a household) and that they are part of a much wider social and political context. If the context is supportive, the outcomes of using a display are likely to be improved; if not, it may simply make the user despondent. At this point one may seem to be straying a long way from the affordances of the display itself, but Hargreaves also points out that:

> devices themselves are able to alter [the] context or at least perceptions of it. ... When negative, the devices can make environmental and financial challenges seem even more insurmountable ... [but] in a larger number of cases, the devices encouraged some interviewees to take stronger action to reduce their own energy consumption, to discuss such matters with family and friends, and to seek further information, advice and assistance from housing associations, appliance retailers and local authorities.
>
> (pp. 39–40)

If someone lives in a dwelling that is difficult and expensive to improve through standard measures, then his/her needs are likely to include advice, expertise and finance; feedback alone is not enough, particularly for people who are already careful in their habits. Smart metering does not provide any of these directly, though it does offer some scope for better diagnosis of the potential for demand reduction. A detailed picture of household demand patterns can be useful in conjunction with advice: even daily or weekly meter readings give a valuable guide to adviser and advisee about what can be achieved and how to proceed (Darby, 2003). The challenge is to elicit useful information from the mass of data that will be available once smart metering is under way; to have the expertise and experience available to guide householders when they need assistance; and to use new metering systems methodically for evaluating the impact of changes in building, appliances and behaviour patterns. This is unlikely to happen unless both supplier and customer are motivated to use the data for these purposes.

Online feedback

Web-based applications for customer feedback are favoured by utilities. They are relatively inexpensive (no costs sunk in the manufacture and distribution of dedicated displays), can be updated rapidly, and ensure that the supplier has access to, and controls, all the information. They can also be used to process data for sending to customers via a range of devices, including mobile phones and personal computers. This could be a promising application for alerting householders to abnormal consumption. Web applications can show householders a great deal of detail over time about their own consumption and about the wider picture: how their usage compares with that of others; or what the demand curve for the nation or region looks like (at times of supply constraint). The recent move by Google into providing energy feedback demonstrates interest from third parties in providing this particular form of energy service.

However, there are limitations, chief among them the difficulty of getting people engaged deeply enough to access the information on a regular basis. It takes extra effort and determination to look up consumption data online compared with the effort needed to check a dedicated display in the home. The UK government response to the latest consultation on smart metering comments that:

> The Government's position remains that a stand-alone display should be provided with the smart meter … the provision of a display is important to securing the consumer benefits of smart metering, delivering real time information to consumers on their energy consumption in a readily accessible form. Whilst … there are … alternative means of information provision … evidence to date suggests they may often be less effective, especially where they require positive action by the consumer to access information. Experience in the USA and Sweden has, for example, shown that where smart meter data has been available online, the usage rate has been low at 2 to 4 per cent of customers.
>
> (DECC, 2009b)

The possibilities for online feedback are evolving, along with support services and customer-relations programmes. Some are proving successful in terms of engagement, but again it needs saying that they do not necessarily need smart meters for this: people can key in their meter readings over a period of time in conjunction with a feedback or advice programme, and there are successful examples of this.[9]

This overview of feedback arrangements shows something of what has been achieved in terms of customer engagement without smart metering. It also points towards what could be achieved through a well-designed 'smarting' of metering systems, *i.e.* a system designed with customer relations and customer learning as priorities. Information on its own may or may not be of any practical use to consumers; it has to be absorbed and tested in particular buildings, in company with particular people, and in particular climatic, regulatory, and political circumstances. Smart metering can greatly improve the information available to both supplier and consumer; however, the challenge is to develop communications that can be used to select the most useful information for the consumer and to combine them with advice and other pointers to enable effective action.

Conclusions

Throughout most of the last century, the electricity or gas meter has been an essential but very modest element of energy infrastructures. The advent of 'smart' metering or advanced metering infrastructure (AMI) is changing that. Smart metering is heavily promoted as an essential part of the transition to lower-impact energy systems, and as a means of customer engagement. For electricity, where most attention is concentrated, it is also seen as a step on the road to the 'smart grid', a highly complex, self-balancing system. At the macro-level, it has been indicated that smart meters can bring about carbon emissions reductions along with better supply management. At the micro-level, the claim goes, they afford better and more frequent information for householders, leading to demand reduction and cost reduction, at the same time as they afford the possibility of electrical load micro-management to the utility. And at meso-level, there is the prospect of improved customer relations, with the 'smarted' meter acting as a communications hub. Despite several years of claims for smart metering, actual implementation at the household level is in its infancy and there is little hard evidence yet on what AMI can actually achieve. A sceptical approach to smart metering was presented that nonetheless recognizes where and how it can assist with customer engagement.

The realities of smart metering are in some ways simple, *e.g.* a smarter meter is still a meter, only one that takes, stores, and transmits measurements at frequent intervals. In other ways, they are highly complex. A vast range of possibilities is opened up by the addition of communications technologies to metering, and these are exploited in different ways in different contexts. A few of these contexts are outlined above, from California in the US to Sweden to the Netherlands. The extent to which customer awareness is invoked varies considerably. Some instances of smart meters have been rolled out with very little attempt (as yet) to engage customers, as in Italy. In the UK, Ireland, and the Netherlands, the business case for AMI relies on successful customer engagement, the markets are more highly liberalized, and the plans for rollout differ accordingly.

There is much to be learned about householder engagement from experience with consumption feedback in the absence of smart meters: how customers interpret and use feedback information; what they wish to see in the future; and how feedback may be combined with effective advice and other support. The qualitative research that is cited shows interest in, and even enthusiasm for, simple and direct messages about energy costs over time, and for relevant, trustworthy comparisons. Smart metering might facilitate these, but further work in real-life situations is needed to validate these claims.

Using the concept of affordances, it can be seen that there are many versions of smart metering that afford different benefits to different actors in an energy system. Definitions and physical detail matter greatly; so do the intentions behind any development in metering and billing. Studying the affordances of a given smart metering plan leads to questions such as: Who is going to benefit and how? Who needs to understand what? Which people and things need to be mobilized to make these communications work, for whom? To date, there has been much expenditure of effort on developing the technical specifications for AMI, but too little on these questions. In assessing the effectiveness of smart metering for customer engagement, the answers depend on how, and for whom, the smart metering is designed. More work is still needed to establish the forms of interface, feedback, narrative, and support that will be most useful in reaching diverse populations. In particular, there is a need to ensure that disadvantaged groups do not suffer as a consequence of developments in metering and tariffing.

Given that smart metering was developed initially to address the need for electrical load control by suppliers, the concept has travelled some distance, gaining support from a wider constituency. This paper has concentrated on smart metering that includes a provision for improving the supplier–user interface, as is the intention in the UK. Demand reduction will not necessarily flow naturally from an improvement in information, but there is the potential to use AMI for demand reduction *if there is a strong strategic intention to do so, and if the social support is there*. The smart meter, already acclaimed as an improver of customer relations, needs to prove itself by compatibility with useful relationships that are not mediated through a screen or a bill, as well as with those that are.

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Endnotes

[1]This is a harsh view of the work of the meter reader, but widely held. Clearly, AMI is not good news for meter readers. In the short-term, the most usual plan seems to be to re-deploy those who do not take voluntary redundancy as installers of smart meters.

[2]Widespread, but hard to verify because of commercial confidentiality.

[3]See http://www.ofgem.gov.uk/e-serve/sm/events/Documents1/Smart%20metering%20briefing%20event%20-%20DECC%20presentation.pdf/.

[4]The problems associated with the increasing public availability of (or hacking into) private household energy data and its revenge effects are outside the scope of this paper, but this will require consideration. Real-time energy consumption data may indicate which households are temporarily uninhabited and also raise civil liberties issues.

[5]For further information on the proposed rollout, see Ofgem E-Serve at http://www.ofgem.gov.uk/E-Serve/Pages/e-serve.aspx/.

[6]Gas displays are unusual, though a few are available.

[7]From Green Energy Options.

[8]This is supported by records of customer calls to UK suppliers conducting large-scale trials. For further information on the UK Demand Research Project, see http://www.decc.gov.uk/en/content/cms/what_we_do/consumers/smart_meters/meter_trials/meter_trials.aspx/.

[9]For example, http://www.imeasure.org.uk and http://www.pumpscheck.co.uk/.