Title: The role of smart meters in encouraging behavioural change - prospects for the UK

Authors: Mari Martiskainen[a] (corresponding author)*, Josie Ellis[a]

[a] Sussex Energy Group, SPRU (Science and Technology Policy Research), University of Sussex, Freeman Centre, Falmer, Brighton, East Sussex BN1 9QE, United Kingdom

* m.martiskainen@sussex.ac.uk, Tel. +44 (0)1273 873630, Fax. +44 (0)1273 685865

Abstract: Growing concerns about climate change and energy security have led to a strong focus on energy efficiency within UK energy policy. At the same time, information and communication technologies (ICTs) have become pervasive in society and this has brought with it new policy options which use them as enabling technologies. One such policy option planned for implementation in the UK is the use of smart meters and real-time displays to encourage people to become more aware of their energy consumption and possibly change their energy-related behaviours. Smart meters and displays by definition link individuals, technologies and society, and their effectiveness is influenced by a range of factors. This paper aims to identify which factors are most likely to contribute to the effectiveness of smart meters and real-time displays in reducing household energy consumption by analysing: a number of perspectives on behavioural change, particularly as they relate to household electricity use; the role of smart meters in the UK energy efficiency policy, including the role of ICTs in energy demand reduction more generally; and the views of a range of key stakeholders.

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1 Introduction

Energy is invisible but important. "Most people have only a vague idea of how much energy they are using for different purposes" (Darby, 2006, p. 3), and yet electricity has played a major part in economic development (Helm, 2004, p.1) with "electric light, electric motors, electronics and other manifestations of electricity" making modern industrial society possible (Patterson, 1999, p.1). Historically, there has been a focus on increasing the supply of energy to meet the growing demands of both industrialised and industrialising societies (Helm, 2004, p.2) but in the United Kingdom (UK) the focus has shifted towards managing demand for energy, initially due to fears of rising energy prices after the oil crises of the 1970s (Patterson, 1999), and more recently due to increasing concerns about climate change and the security of energy supply (DTI, 2007, p.6)[1]. Household energy consumption contributes to around 28% of UK's carbon dioxide emissions (CO2) emissions (DTI, 2007), and the UK government has a target to reduce CO2 emissions by 60% by 2050 compared to baseline year 1990 (DTI, 2007). Framework for the emissions reduction target is set in the Climate Change Bill which includes measures such as annual carbon targets (HM Government, 2007).

At the same time, there is a growing awareness of the roles that Information and Communication Technologies (ICTs) can play in energy systems (Erdmann et al., 2004, Knowles, Goodman, 2005, Laitner, 2000). Although the direct impact of ICTs on energy is to increase consumption because they use energy and their use is growing (Koomey, 2007), several researchers have argued that ICTs could indirectly reduce demand for energy by for example improving efficiency (Young, 2006), providing information to encourage more sustainable consumption patterns (Erdmann et al., 2004), and facilitating 'e-materialisation' (Erdmann et al., 2004, p. 9, Wilsdon, Miller, 2001, p. 22), which is a structural shift in the economy from energy-intensive products to less energy-intensive services.

The focus of this paper, energy consumption in the household sector, is an issue not only relevant to the UK, but also to other countries, many of whom are expecting to see a deep increase in energy consumption over the coming years (IEA, 2008). A renewed focus on reducing demand for energy, as well as diversifying and 'greening' supply of energy, combined with the use of ICTs as key enabling

[1] As of 28th June 2007, the Department of Trade and Industry (DTI) was superseded by the Department for Business, Enterprise and Regulatory Reform (BERR).

technologies, brings with it new policy options and new complications to consider. Technical fixes to housing stock have been incorporated to UK's energy efficiency policy for some time but considering changes to user behaviour is a relatively new addition to policy thinking. One example of a policy which relies on the use of ICTs as an enabling technology to reduce demand for energy is the introduction of smart meters and real-time displays (DTI, 2007) as a potential way of managing energy 'better'. The UK government has announced a national roll-out of smart meters in the coming decade and is, together with major energy supply companies, trialling various smart meter and display technologies via its Energy Demand Research Project (EDRP) which involves over 50,000 UK households (Ofgem, 2009).

Previous research has highlighted the complexities linked to the study of household energy consumption (see for instance a review by Abrahamse et al., 2005) and that interdisciplinary research is required to understand household behaviours related to energy consumption (Steg, 2008). This paper explores the roles that ICT technologies can have in the energy system by making people more aware of their energy use and potentially reducing household energy consumption. First the paper outlines the methodology and theoretical framework used in this paper. A framework of key trends in domestic energy consumption in the UK and the behavioural challenge of household energy consumption are outlined, including socio-economic behavioural models. The paper then moves on to explaining the UK's energy efficiency policy and how technologies such as ICTs could be implemented to encourage behavioural change. Reflecting on the theoretical framework and semi-structured interviews, three levels of stakeholder views are identified and explained: 1) economic, 2) socio-psychological and 3) technology-based system-level views. Finally, the paper concludes by outlining lessons learnt for UK energy policy and identifying areas for future research.

2 Methodology

This paper analyses economic, socio-psychological and technology-based perspectives on behavioural change and how they interact. The views of key stakeholders are used to identify which factors are likely to contribute to the effectiveness of ICTs in potentially reducing household energy consumption. A case study strategy of research was followed, in which evidence gathered from multiple sources is triangulated so that the different sources corroborate each other (Yin, 2003). This paper draws on the results from two studies, a literature review of behavioural research theories and studies to provide understanding on key issues and strategies for affecting energy consuming behaviours in UK homes (the full review is available from Martiskainen, 2007) and an empirical study examining the role of ICTs and how they, as forms of possible behavioural change measures, could be implemented in the UK, and what roles ICTs in general could play in the wider energy system.

The literature review was based on academic papers, 31 experimental intervention studies, policy documents, and private sector and non-governmental organisations' reports, involving a comprehensive review of technical and informational energy efficiency options, as well as behavioural theory and policy measures (see Appendix A for a summary of studies). In addition, results from semi-structured interviews with key stakeholders were analysed to determine how smart meters as possible behavioural change measures could be implemented in the UK. Semi-structured interviews were chosen because they allow people flexibility in their chosen responses while still providing some structure for comparability between interviewees (May, 2001, p. 123). There were 10 interviews in total, each interview lasting for between 40 and 60 minutes. The interviewees were chosen as representatives of a range of different views about ICTs including energy suppliers, smart meter and real-time display manufacturers, government officials, academics, and non-governmental organisations (see Appendix B for a list of interviewees). Some interviewees requested anonymity and to achieve this all interviewee comments will be non-attributed. Evidence from the literature review and the semi-structured interviews were analysed to answer the following key questions:

- How can households' energy-using behaviours be understood?
    - How are these behaviours formed and what influences them?
    - What are the options for encouraging behavioural change?
    - Which behavioural change measures are likely to be effective in the UK context?
- The role of ICTs as a potential for encouraging behavioural change?
    - Strengths and weaknesses of different technologies?
    - What type of information could/should be displayed via ICTs?

- What lessons are learnt for government policy and future direction regarding ICTs and energy efficiency?

3 Domestic energy consumption trends in the UK

There are three aspects to energy consumption in UK homes, a) the structure and quality of the housing stock b) the energy performance of the appliances installed within the houses, and c) the behaviours of the householders themselves. This paper mainly concentrates on the behavioural aspects of households but will also outline the state of UK's housing stock and general trends in household energy consumption as a background to the behavioural challenge and UK's energy efficiency policies.

3.1 UK housing stock

There are almost 26 million homes in the UK, two thirds of which are estimated to be in existence in 2050 (Boardman et al., 2005). The Standard Assessment Procedure (SAP) rating is used to assess the energy performance of buildings, based on the house type and layout. The SAP rating is presented on a scale from 1 to 100, with energy efficient houses having a score of 80 or more and a score of 100 indicating a highly energy-efficient home (Wright, 2004). Even though most new homes built in the UK achieve ratings of 80 or above (Roberts, 2008, Wright, 2004), there are approximately 2 million UK homes which have a SAP rating below 30 (Boardman et al., 2005).

Dwelling age	**Average SAP rating**	**% of total housing stock in 2005**
Pre-1919	39	58%
1919 to 1944	43	
1945 to 1964	48	
1965 to 1980	51	23%
Post-1980	61	19%

Table 1: Average SAP rating of English houses (DCLG, 2007, Immendoerfer et al., 2008)

Existing housing stock in particular is an issue with energy related emissions (Roberts, 2008) and many people can be seen to be 'locked-in' to poorly built and inefficient houses, thus having little control over the emissions their homes produce. Houses in the UK may be inefficient when it comes to insulation for instance, but generally they are considered to be more comfortable than 30 years ago. The use of both central heating and electrical appliances, including ICTs, has risen considerably since the 1970s. For instance the average internal temperatures in centrally heated UK homes were 13.8 degrees Celsius (^oC) in 1970, compared to 18.2 ^oC in 2004 (BERR, 2008a), meaning that over half of today's household emissions are linked to space heating.

Around 10 million new homes, equal to around 220,000 homes each year, are estimated to be built by 2050 (Boardman et al., 2005). The UK government has indicated that by 2016 all new homes should be zero carbon (DCLG, 2006a, 2006b, 2008). However, existing UK Building Regulations, particularly Part L which covers energy efficiency standards, are not always vigorously followed by the building trade, or more importantly being enforced by authorities. This was demonstrated by a survey of builders which found that Part L is not a priority for house builders and there are several areas which do not comply with the regulations, such as u-values of constructional elements, internal lighting, and windows (Future Energy Solutions, 2006, p. 38). Given that the rate of new built houses is relatively low compared to the existing housing stock, upgrading the existing housing stock has an important part in how UK's emissions will shape in the coming years (Foresight Sustainable Energy Management and the Built Environment Project, 2008).

In addition to the quality of the housing stock, the system which links UK homes to the wider energy metering network is also rather dated. 'Basic' domestic meters accurately measure the amount of electricity and gas supplied to homes but they do not record time-of-use of energy and cannot be remotely controlled and need to be physically read to obtain metering data, making the system as a whole inefficient. Most of the domestic UK energy metering stock has not radically changed in over a century, despite consumer electronics and ICTs being widely adopted in many other fields (Owen, Ward, 2006).

3.2 The role of appliances in household energy consumption

Households' purchasing and use of electrical appliances has increased considerable over the past decades, partly as a result of trends in consumerism and fashion. While ownership of some household appliances has remained relatively steady over the last 30 years (such as irons and TVs) and some have fallen slightly (such as coffee makers), appliance ownership in general has increased (see Figure 1) (DTI, 2007). In 1970 total electricity consumption by household domestic appliances was 2,922 thousand tonnes of oil equivalent (toe), while in 2005 this figure had risen to 7,388 thousand toe (BERR, 2008b). In particular, the use of consumer electronics and ICTs are increasing and a recent Energy Saving Trust (EST) report predicted that they will use the equivalent energy of 14,700 megawatts of installed power plant capacity by 2020 (Owen, 2007, p. 3).

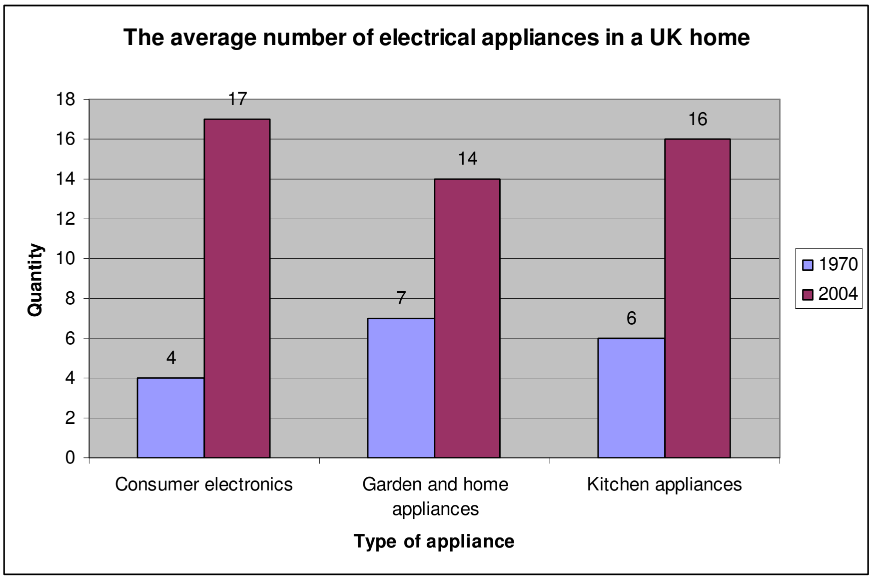

Figure 1: Trend in electrical appliance ownership 1970 and 2004 (DTI, 2007).

Despite the fact that most modern appliances have improved energy efficiency, they also have features which can counteract efficiency savings. For instance standby modes have been linked to increased energy wastage (EST, 2006). This is the case particularly in the UK, where around 71% of consumers regularly leave appliances on standby and 63% leave lights on in unoccupied rooms (EST, 2006). While white goods are labelled according to their energy usage and almost 70% of cold appliances sold in Europe are rated at the highest level for their energy efficiency, majority of consumer electronics, however, remain without energy labelling (Bertoldi, Atanasiu, 2007).

3.3 How we behave determines how much energy we consume

In addition to the housing stock and appliances, energy consumption from the household sector is also linked to the behaviours of those who occupy the houses. Energy consuming behaviours are actions taken in the home which have direct links to either electricity or gas being consumed at the point of usage. In addition to actual usage of appliances, purchasing behaviours form another in-direct, albeit an important aspect to domestic energy consumption. Therefore household's purchasing behaviours, and the options available to them, have to also be taken into consideration. Energy consumption in itself is not behaviour, but rather a consequence of behaviours (Becker et al., 1981). In the context of this paper, energy behaviour, or more accurately behaviours, are defined as gas and electricity use in the home. These include actions such as purchasing and using electrical appliances, using lighting and setting the thermostat level. The apparent invisibility of domestic energy use often means that households are detached from their gas and electricity use, especially if they pay their bills by direct debit (Roberts, Baker, 2003), a payment that goes automatically from their bank account. This can lead to little knowledge about how much gas or electricity people actually use in their homes (Roberts, Baker, 2003). In order to reduce emissions from the residential sector, both housing stock and user behaviours need to be changed towards more sustainable and low emitting options.

4 The behavioural challenge in relation to household energy use

In order for the UK Government to introduce behavioural change measures in its energy policy, there is a need for more evidence on which measures would be the most influential in UK conditions (DTI, 2007). For policy makers to be able to design effective behavioural change measures, they need to identify how our behaviours are formed and how they could potentially be influenced. Energy behaviours are influenced by wider societal, as well as personal factors, including both internal (attitudes, beliefs, norms) and external factors (regulations, institutions and society as a whole) (Jackson, 2005), and more recently research has highlighted factors such as cultural norms and fashion (Owens, Driffill, 2008). In order to change people's behaviour, both internal and external factors need to be taken into consideration (Gärling et al., 2002). Economists and social-psychologists have developed various models and theories in order to understand how behaviours are formed and how they could be changed. An extensive review of models and theories relating to sustainable consumption behaviours is available from Jackson (2005), and the theories and behavioural models discussed in this paper are largely based on this review.

4.1 Models for understanding behaviour

One of the most widely used behavioural theories is the 'rational choice' model of neoclassical economics. This theory is based on the notion that people weigh the expected costs and benefits of different actions and choose those actions which are most beneficial or least costly to them (Jackson, 2005). Rational choice theory was used as a basis for much of the 1970s energy conservation research, with researchers using measures such as information campaigns and workshops as tools for highlighting the benefits of energy saving measures (see for example Becker, 1978, Bittle et al., 1979, Bittle et al., 1979-1980). Later environmental research has used models such as the Theory of Planned Behaviour which is based on the principle that person's beliefs on how difficult or easy a behaviour is influences his/her decision to conduct that behaviour, including a strong notion on person's ability to choose his/her actions (Jackson, 2005). The Theory of Planned Behaviour has been one of the most widely used in pro-environmental behavioural research, including research in recycling, travel mode choice and energy consumption (Jackson, 2005). Despite the wide use of these models, they are however limited in their scope as they do not account for factors such as social norms, emotions and habits, i.e. the actions people undertake without really having to think about them. Habits such as turning the lights on/off, using appliances and heating systems are especially important regarding household energy behaviours. Furthermore 'bad' habits such as leaving appliances on standby and the lights on are forecast to cost the UK economy around £11 billion by 2010 (EST, 2006).

One model which highlights the influence of habits on behaviour is Triandis' Theory of Interpersonal Behaviour. It was developed in 1977, but it differs considerably from the general 1970s behavioural research trend of rational choice theories (Jackson, 2005). According to Triandis' model, behaviour in any given situation is a function of what a person intends, what his/her habits are, any situational factors and the conditions in which the person operates (Jackson, 2005), taking into account person's beliefs about what the outcome of their behaviour will be.

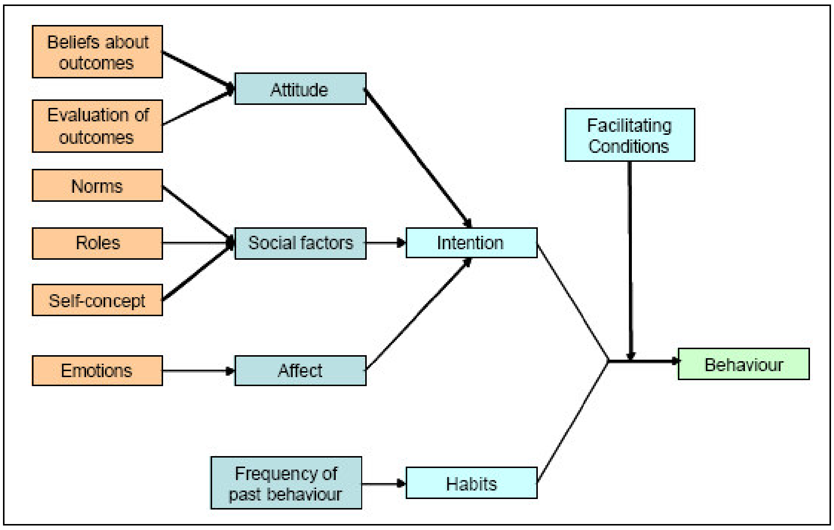

Figure 2: Triandis' Theory of Interpersonal Behaviour (Jackson, 2005, p. 94)

Triandis' model has been used in some experimental environmental research, for instance in defining the role of habits in car use (Bamberg, Schmidt, 2003), but as a fairly complex model it has not been used very widely in experimental research (Jackson, 2005). However, it offers a comprehensive explanation of the complexities involved in behavioural research and the variables that influence behaviour.

4.2 Changing energy consuming behaviours

In order to change habits and routines, old behaviours need to be broken down before new ones can form (Stern, 2000). Habits and routines can be difficult to break as they are ingrained in people's behaviour - hence selecting the best measures to encourage behavioural change in domestic energy consumption can be challenging. Previous research (Abrahamse et al., 2005, Darby, 2006) and our literature review show that several intervention measures have been tested over the years in order to change households' energy consumption (these studies are summarised in Martiskainen, 2007). Several of the intervention studies were based on rational choice theories and the notion that as long as people were given right information about their energy consumption and its cost, they would make rational choices over that information (Jackson, 2005) and behave accordingly.

However, as Triandis' model shows, behaviours are complex and intervention measures should go beyond basic rational choice theories. Interventions, such as giving people certain type of feedback on their energy consumption, can make people aware of their routine behaviours (Darby, 2006). Feedback on energy consumption can take several forms and measures include techniques such as giving households either daily, weekly or monthly feedback on their energy consumption and using methods such as comparative monthly bills and goal-related feedback or ICTs such as direct displays or smart meters (Darby, 2006). A smart meter measures energy use electronically and communicates this data to other devices, which enables a range of new functions such as remote meter reading, time-of-day tariffs and real-time usage information. More importantly, these technologies allow feedback to be tailored to each user's individual requirements, making it possible to present feedback in the easiest, simplest and most convenient way to the householder (Darby, 2006).

Traditionally energy meters in the UK have been fairly low-tech and positioned out-of-sight, hence the data they provide is often not seen by the householders (Owen, Ward, 2006). Real-time visual displays provide a solution to this problem by displaying the data via a digital screen from energy meters or mains electricity cables, often wirelessly so that it can be positioned anywhere in the home. Real-time displays can either clip on to existing meters and display the available data, or use the accurate and more detailed data provided by smart meters. So far the provision of energy-related data by smart meters and real-time displays has been studied mainly within narrow disciplines and there have been limited trials with varied results (Abrahamse et al., 2005, Fischer, 2007). Early indications from studies conducted for instance in the US and Norway on smart meter systems suggest that households who receive feedback on their energy consumption could save up to 15% of their energy consumption (Darby, 2006). However, there is a need for more research along many dimensions to understand the issues involved, especially which behavioural change measures could produce the largest long-term energy savings and how technologies such as smart meters and display units could be incorporated in UK's energy policy.

5 The role of ICTs in UK energy policy

According to a report for the Institute for Prospective Technological Studies (IPTS), ICTs "pervade all sectors of the economy, where they act as integrating and enabling technologies" (Erdmann et al., 2004, p. 3). However, several researchers have observed that although the ICT revolution has touched the energy sector, its potential impact has not been widely recognised so far and even less so when the explicit focus is on reducing carbon emissions (Pamlin, Szomolányi, 2006, Young, 2006). In the energy system, ICTs directly increase demand for energy because not only do they use energy, but also the use of ICTs is increasing (Koomey, 2007). The impact of ICTs on energy demand varies depending on the context and they could enable a decrease in energy consumption overall (Erdmann et al., 2004, Knowles, Goodman, 2005). ICTs have been used in the energy system for trading at the wholesale level, thereby improving the efficiency of trading since the UK electricity market was liberalised in 1998 (Helm, 2004). They have also improved the efficiency of energy generation and distribution (Erdmann et al., 2004).

There is a growing interest in the role of ICTs in supporting the growth of microgeneration (the generation of low or zero carbon heat and electricity in the smallest scale) by reconfiguring central grid systems and integrating and controlling microgeneration devices and networks (Erdmann et al., 2004). One way to manage a number of microgeneration devices is to treat them as a virtual power plant (VPP), whereby an energy services company manages a number of microgeneration devices remotely to balance supply and demand (Watson et al., 2006). VPPs require ICTs to coordinate and control their constituent components (Erdmann et al., 2004). ICTs called Dynamic Demand Control (DDC) devices can also actively manage loads in an energy system, switching electronic devices on and off depending on the overall load on the system (Market Transformation Programme, 2006). This not only reduces demand but also reduces the peak load on the electricity system by shifting loads, which could reduce the overall amount of electricity generation required.

Furthermore, ICTs enable low-cost metering and communication systems and in particular can encourage households to adopt more sustainable consumption patterns (Erdmann et al., 2004), by providing feedback about their energy consumption via smart meters and real-time displays. Hence ICTs could be key enabling technologies in improving energy efficiency and enabling energy savings (Erdmann et al., 2004). However, researchers agree that this may only be achieved if it is guided by appropriate policies and strategies (Erdmann et al., 2004, Knowles, Goodman, 2005, Pamlin, Szomolányi, 2006).

Key policy instrument for household energy efficiency in the UK is the Carbon Emissions Reduction Target (CERT) (previously known as the Energy Efficiency Commitment (EEC)), which began in 2002 and runs in three year phases, with the latest phase of CERT taking place in 2008-2011. CERT requires energy supply companies to undertake energy efficiency measures in the household sector, which have mainly included technical measures such as loft and cavity wall insulation, and energy efficient lighting (Defra 2007). However, ICTs such as smart meters and real-time display units can have a potentially important role in CERT. The Climate Change and Sustainable Energy Act 2006 (HM Government, 2006) has made it possible to include behavioural change measures, as well as microgeneration, within UK's energy efficiency policy, and these are expected to be introduced during CERT. There is relatively little evidence on how much various behavioural change measures could contribute towards the total CERT targets and further research is required in this area. The UK government is also planning to introduce display units during 2008-2010 as a short-term measure prior to wider roll-out of smart meters. The Energy White Paper 2007 states that "within the next 10 years, all domestic energy customers will have smart meters with visual displays of real-time information that allow communication between the meter, the energy supplier and the customer" (DTI, 2007, p. 64). The short-term measure of providing display units is estimated to deliver savings of 300,000 tonnes of CO2 emissions per year by 2020 (DTI, 2007).

While other countries such as US, Norway, Italy, Canada and Sweden have introduced smart meters to domestic customers, the UK is still in early stages of development. It could also be argued that the UK has been slow in comparison to other countries to deploy various feedback measures such as better bills, and previous research has suggested that these should have been introduced much earlier than the government's planned schedule (Roberts, Baker, 2003).

6 Results from stakeholder interviews

Energy use has key impacts on our society, be it economic, societal or environmental. In such an economically and politically important system with considerable inertia, the views of key stakeholders are likely to be an important factor in determining the success or failure of policy options such as the roll-out of smart meters and real-time displays. This section summarises results from ten key stakeholder interviews, each of which lasted for between 40 and 60 minutes. The interviewees represent a wide range of different sectors that either have an interest in or direct involvement with smart meters and real-time displays. These included energy suppliers, smart meter and real-time display manufacturers, government officials, academics, and non-governmental organisations (see Appendix A for a list of interviewees). There was considerable variation in the views of key stakeholders about the proposed introduction of smart meters and real-time displays, although some common themes emerged, as follows.

Most interviewees considered the prospects for smart meters and real-time displays being rolled out in the UK to be good, in agreement with a recent analysis that "smart metering will and should happen" (Owen, Ward, 2007, p. 4), and most also felt that smart meters and real-time displays were likely to have some impact on energy use. Interviewees agreed that smart meters are an improvement on the electro-mechanical meters found in most UK homes and the key strengths are that they can provide real-time feedback to users and to suppliers, which can then be used in a variety of ways. Views about the future of displays were more varied. One interviewee commented that "displays don't have to arrive at all" but that they are likely to because they are low cost and have the potential for early carbon savings, which will help the government meet their short-term targets for reducing carbon emissions. An interdisciplinary analysis shows that different views were influenced at least in part by respondents' underlying assumptions about the basis of people's motivations as being predominantly *economic*, *socio-psychological*, or *technology-based system level* views.

6.1 Economic views

Taking an economic perspective on behavioural change, one respondent took a purely rational choice theory position by saying that the key strength of real-time displays is the provision of better information for consumers so that they are better informed and can make "better judgments", enabling them to exercise rational choice and minimise their costs. According to this rationale, real-time information about consumption and cost should be displayed as a minimum to maximise the effectiveness of smart meters and displays. However, as previous literature shows, information alone has not been proven to be effective enough to change households' energy consuming behaviours (see for example Abrahamse et al., 2005, Darby, 2006). Other interviewees in this perspective emphasized that cost is "one of the key prohibiting factors", and not only the cost of providing and installing smart meters, but also the cost of updating "data handling and billing systems" so that they can store, process and use the data. According to one respondent, estimated costs for introducing smart meters range from 7 to 10 billion pounds.

In terms of possible future directions, some respondents thought smart metering and real-time displays "should be left to the markets" because "there is not one perfect smart meter solution". In response to concerns raised about the competitive market as a barrier to the successful implementation of smart meters and displays, they argued that the market would deliver different solutions to different consumers whereas blanket regulation would be more likely to produce a "one size fits all" solution. The economic rational choice model tends to dominate commercial and policy-making decision processes (Jackson, 2005). However, for programmes such as the introduction of smart meters and real-time displays, which link individuals, technologies and society, some stakeholders felt that a range of other factors must be considered, including socio-psychological motivations such as habits and routines as discussed in section 4, and technological and institutional drivers and constraints.

6.2 Socio-psychological views

Those who took a socio-psychological perspective tended to accentuate the importance of human factors to the effectiveness and potential future of smart meters and real-time displays. While one interviewee suggested that there are "lots of low hanging fruit" in terms of consumers saving energy, another argued that "whatever you do, some customers won't care and other customers will" due to the importance of psychological factors such as attitude.

Some of those questioned explained that "instant information on electricity use seems to have a wake up effect" and that therefore interaction with the display would be crucial, consistent with the importance of psychological factors such as the need to ‘unfreeze’ habitual behaviours and make an emotional connection with the display. According to this view real-time displays allow consumers to see their real-time energy use clearly for the first time, enabling them to become aware of habitual behaviours and the socially-embedded, invisible nature of energy. Various strategies for achieving this effect were suggested, from making feedback appealing, intuitive and simple, to ensuring that people need to interact with it for other reasons by including features such as a clock, or travel information.

Some respondents felt that there was uncertainty about how the design of displays might influence behavioural change. It is not yet clear what information should be displayed, how it should be displayed, and where the display device should be situated to encourage the greatest change in behaviours (Fischer, 2007). These factors could be important for changing people’s energy-using behaviours via psychological mechanisms such as breaking old habits and forming new ones. Several interviewees also suggested that consumer engagement would be a key issue, with one describing “how engaged the consumer is” as the most important factor and suggesting that education programmes and awareness-raising are therefore crucial. Another respondent identified the “need for a longer term change of culture”. From this perspective, psychological and social factors are likely to be important for encouraging the consumer engagement and long term cultural change that are required to reduce household energy consumption.

While some interviewees talked about education, others focussed on marketing. One suggested that “marketing links would need to be made” to ensure that energy efficiency becomes “a factor in buying decisions”. Other respondents suggested that real-time displays could “create market demand for low energy products” and that they may be “a springboard” for other innovations such as “tailored advertising” delivered to you, depending on your home energy use patterns, and “home energy management systems” where a central system manages your home energy use by controlling appliances and switching them on and off as necessary. However, these sorts of innovations will depend on consumers’ levels of understanding and on targeting the right products to the right consumers.

6.3 Technology-based system-level views

Some stakeholders held the view that whether smart meters and real-time displays are effective or not will depend on their specification and on resolving current uncertainties about which technologies to use. For example, some respondents made a clear distinction between smart meters and 'clip-on' real-time displays. Advocates of clip-on displays thought that providing consumers with real-time information in a prominent place in the home is what would make smart meters and real-time displays effective. Owen and Ward (2006) have argued that smart meters alone would not have this effect because they are usually positioned out-of-sight. Darby has suggested that providing clip-on displays could facilitate energy demand reduction in households and that "any development of 'smart metering' needs to be guided by considerations of the quality and quantity of feedback that can be supplied to customers" (Darby, 2006, p. 4). Important factors for the effectiveness of displays were identified as the information that is displayed, how it is displayed, the way the devices look and ease of use, and where the devices are situated or whether they are portable.

However, the Energy Retail Association (ERA), an organisation that represents Britain's domestic electricity and gas suppliers, has argued that providing clip-on displays without smart meters will divert resources away from smart meters and may confuse consumers because the data provided by clip-on displays can be inaccurate (Energy Retail Association, 2007b). Clip-on displays were also described as "limited" because communication from the meter or the mains electricity cable to the display is only one-way, which means that the display is "not interactive" and therefore unlikely to keep people engaged. Advocates of this view thought that two-way communication between smart meters and displays was important because this would allow the supplier to "aid the consumer via new products" and communicate with people "in ways that suit them". Important factors for the effectiveness of smart meters were argued to be accuracy of information and the capabilities enabled by two-way communication between smart meters and utilities.

Thus there is a debate between key stakeholders about whether clip-on displays should be rolled out quickly to encourage energy demand reduction in a shorter timescale (Darby, 2006) as proposed by the government (DTI, 2007) or whether accurate real-time displays should be rolled out with smart meters to avoid disputes about inaccurate data (Energy Retail Association, 2007b). This provides an example of how the views of key stakeholders are likely to influence the future of smart metering and real-time displays.

There are also potential system-level implications from the outcome of this debate. Clip-on displays can only receive information from meters and thus communication is one-way (Owen, Ward, 2006), which does not require any changes to the current metering stock. In contrast, displays that directly communicate with smart meters and then between the meter/display and the energy supplier imply two-way communication, which would necessitate system adaptation of software systems, organisational structures and institutions. It would also enable new functionality such as the provision of personalised messages from energy companies to householders to encourage them to save energy depending on their actual energy use (Lees, 2007) and according to one stakeholder, "a more useful relationship between customers and energy suppliers". This illustrates the co-evolutionary nature of technologies and behaviours and how there can be links between micro and macro level processes (Rip, Kemp, 1998). At a macro level two-way communication would necessitate widespread system changes but it would also enable new smart meter functionalities and new interactions between technologies and behaviours on a micro level. Within this framework, technology diffusion can be viewed as a transformation process whereby new technologies are incorporated into new technological regimes, new regimes supersede old ones, and "behaviours, organization, and society have to rearrange themselves to adopt and adapt to the novelty" (Rip, Kemp, 1998, pp. 387-389).

In addition to the specification of the technologies themselves, the strategy for their roll-out could affect their success in promoting behavioural changes. According to one respondent, there is a difficult trade-off between rolling-out smart meters quickly to ensure that the potential benefits are realised as soon as possible, and delaying roll-out to ensure the technology is sufficiently mature. Smart metering technology as well as the associated costs are evolving rapidly (Lees, 2007) and some interviewees felt that there is a "significant risk" that the speed of technological change will mean that today's smart meters will rapidly become outdated and could be expensive to update. Additionally, as one respondent commented, the UK government does not have a good track record for managing large technology-based projects and therefore if the rollout was unsuccessful or more costly than expected, it would be "a massive fiasco". This provides an example of a difficult control problem in which governments have the most control over technological choices when technologies are new and the least is known about their impacts (Rip, Kemp, 1998).

6.4 Lessons learnt for UK energy policy

Several of those interviewed expressed concern that the government should take a more cautious approach and wait for the results from trials and analysis to find out "what works" before developing smart metering policy, particularly given the risk "of buying into the wrong technology" and since smart metering technologies are changing very quickly. These respondents felt that the government should consult and then set "appropriate minimum standards" to ensure flexibility and maximum impact.

Rolling out smart meters and real-time displays to every household in the UK also requires a high degree of industry coordination but in the UK there are competitive markets for wholesale, retail, and domestic electricity, as well as for metering services. Some stakeholders pointed out that under these competition rules, suppliers cannot collaborate to find the optimal solution for rolling out smart meters.

In particular, several interviewees expressed concern that competition in metering services means that there are no market incentives to make smart meters compatible between suppliers. However, in a competitive market consumers can change energy suppliers. If a supplier installs a smart meter in a home and then the occupant changes to another supplier, the smart meter becomes an expensive 'stranded asset' to the first supplier, who is no longer benefiting from it being there. Compatibility was seen as a major issue before the 2007 Energy White Paper (DTI, 2007) but now energy supply companies are working together to define minimum specifications for the basic functionality required by a smart meter and how to ensure that they are compatible with different suppliers' systems (Energy Retail Association, 2007a). However, some respondents felt that this issue will require government action to ensure that there is a coherent industry approach. One option would be to transfer ownership of meters to the network operator, which has been the case for most international smart meters rollouts (Owen, Ward, 2006).

Some respondents also argued that ensuring interoperability in a competitive market is likely to lead to "lowest common denominator" smart meters. They pointed out that suppliers do not have an incentive to produce expensive smart meters with complex specifications if the benefits are likely to be appropriated by other suppliers when a consumer decides to change from one supplier to another. Since the technology is likely to be in place for at least 15 years, one interviewee suggested that smart meters should be designed to be 'future proof'. They need to be compatible with future technologies and easy to update. "Modularity and flexibility" in smart meter designs were felt to be important features for achieving this. Owen and Ward have also reported that "future flexibility and adaptability remain important principles in an environment which is extremely dynamic in both technical and cost terms" (Owen, Ward, 2007, p. 22).

Even if the problem of interoperability is solved, several respondents suggested that the UK government have not made policy clear yet and that uncertainty about future policy could be a barrier to introducing smart metering in a competitive market and could lead to inaction on the part of suppliers. Research suggests that energy suppliers are unlikely to invest in expensive smart meters if there is uncertainty about what requirements will be stipulated by future government policy (Owen, Ward, 2006).

The potential influence of competitive market processes and future government policy on the specifications of smart meter technologies provides another example of the significant influence of interactions between individual technologies and institutional factors. Thus the ability to enable behavioural change via smart meters and real-time displays is dependent on both technological and wider system choices.

Interviewees agreed that there need to be complementary policies to address "the whole issue of energy efficiency" and that smart meters and displays should work alongside other strategies for reducing domestic energy consumption, such as improving the energy efficiency of electrical appliances, and installing insulation. There was consensus that all strategies were important and likely to develop over time, but one respondent stressed that "it needs action from all parties to bring it together".

Respondents felt that smart meters and real-time displays could encourage people to change their behaviour, especially with the introduction of time-of-day pricing to give people a financial incentive. Several people pointed out that the amount of energy used by appliances in particular depends not only on their energy efficiency, but also on their size. According to one interviewee, an energy efficiency standard "doesn't discourage you from buying bigger, it just improves the energy efficiency" of that product. This was used as an argument for integrated policies that work together to achieve genuine improvements in energy efficiency. These arguments support the conclusion that although appealing to personal responsibility and encouraging behavioural change are important because a large proportion of energy use is behaviourally determined, measures based on improving energy efficiency are also necessary because some behaviour is determined by the available technologies.

Smart meters can measure energy exported as well as imported, which could encourage more micro-generation because consumers could both buy electricity from the grid and sell it back (Owen, Ward, 2006). Interviewees felt that although there are issues to be resolved such as how much people should get paid for the electricity they generate, smart metering and micro-generation should be "mutually enforcing".

Most interviewees felt that the future of smart meters depends on future policy. One interviewee highlighted that what happens after CERT will be "a key factor". For example, if the government introduces a 'supplier obligation' based on a 'cap and trade scheme', in which energy suppliers have to ensure that average emissions per customer stay below a specified level, then suppliers "will have to look at behavioural measures" to meet their obligation. This would shift the responsibility for working out how to engage with customers onto the energy companies. According to the same respondent, companies are likely to introduce innovative tariffs in response to this sort of policy.

7 Conclusions

Households' energy consuming behaviours can be complex and are influenced by several factors such as cultural and societal settings, country-specific regulations and on a more domestic level the type of housing people live in and how they behave in their homes, including the purchase and use of various household appliances. Research suggests that providing households better feedback on their energy consuming behaviours can make them more aware of their every day actions and how these link to energy consumption. Technologies such as ICTs can be viewed as being both harmful and beneficial in relation to energy consumption. They can on one hand increase consumption via increased amount of electrical appliances, but at the same time ICTs can be at the forefront of new innovations which provide better feedback to households on their energy consumption via technologies such as smart meters and real-time display units.

Our research shows that there are three pre-dominant views on the implementation of smart meters and real-time display units in the UK, as summarised in the table below.

	Key theoretical background	**Example argument**
Economic view	Rational Choice Theory	- Real-time displays provide better information for consumers so that they are better informed and can make "better judgments".
Socio-psychological view	Extended models such as Triandi's Theory of Interpersonal Behaviour	- Real-time displays allow consumers to see their real-time energy use clearly for the first time, enabling them to become aware of habitual behaviours and the socially-embedded, invisible nature of energy.
Technology-based system-level view	Extended models such as Triandi's Theory of Interpersonal Behaviour	- At a macro level two-way communication would necessitate widespread system changes but it would also enable new smart meter functionalities and new interactions between technologies and behaviours on a micro level.

Table 2: Key example views from stakeholder interviews

Issues such as consumer engagement, marketing strategies, cultural changes and the way feedback is presented (making it appealing, intuitive and simple) were prominent in the stakeholder interviews. Respondents felt that smart meters and real-time displays could encourage people to change their behaviour, especially with the introduction of time-of-day pricing to give people a financial incentive. However, it was noted that the energy efficiency of households should also be improved by implementing other measures such as insulation and improving the energy efficiency of appliances. Furthermore, there was a clear debate between key stakeholders about whether clip-on displays should be rolled out quickly to encourage energy demand reduction in a shorter timescale as proposed by the government or whether accurate real-time displays should be rolled out with smart meters to avoid disputes about inaccurate data.

The analysis shows that taking an interdisciplinary perspective highlights important considerations that may be overlooked under the assumptions of rational choice that often underpin commercial and policy-making decision processes. Some important policy considerations for smart meters and displays are the need to 'future proof' the technologies by designing in modularity and flexibility, the importance of analysing the impacts of technology choices from a system perspective as well as at the micro level, and the need for smart metering policies to be fully supported by and integrated into other energy policies. Despite widespread support for smart meters and real-time displays, there are still uncertainties and questions about a range of issues, including, but not limited to:

- Which smart meter and real-time display options are cost effective
- What is technically feasible
- What is effective in terms of changing behaviour, and changing it for the long term
- How to foster public acceptance and engagement

There is a need for further empirical, interdisciplinary research to understand how smart metering and display technologies will influence households' energy consuming behaviours in practice, and to gain a greater understanding of the interactions between technologies and behaviours in society more generally.

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