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Martin Pullinger[a], Heather Lovell[b] & Janette Webb[c]
[a] School of Informatics, University of Edinburgh, Informatics Forum, 10 Crichton Street, Edinburgh EH8 9AB, UK
[b] School of GeoSciences, University of Edinburgh, Drummond Library, Drummond Street, Edinburgh EH8 9XP, UK
[c] School of Social and Political Science, Institute of Governance, University of Edinburgh, Chisholm House, High School Yards, Edinburgh EH1 1LZ, UK

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Influencing household energy practices: a critical review of UK smart metering standards and commercial feedback devices

Martin Pullinger[a]*, Heather Lovell[b] and Janette Webb[c]

[a]*School of Informatics, University of Edinburgh, Informatics Forum, 10 Crichton Street, Edinburgh EH8 9AB, UK;* [b]*School of GeoSciences, University of Edinburgh, Drummond Library, Drummond Street, Edinburgh EH8 9XP, UK;* [c]*School of Social and Political Science, Institute of Governance, University of Edinburgh, Chisholm House, High School Yards, Edinburgh EH1 1LZ, UK*

The smart metering systems currently being installed in UK households support devices that give feedback aimed at encouraging behaviour changes, specifically to reduce energy demand and spending on energy. Detailed standards specify the minimum technical capabilities of the smart meters and feedback devices. In this paper, we assess the extent to which these standards enable feedback that is likely to be effective in reducing demand. Latest research in this field, drawing on theories of social practice, suggests that feedback devices assume and rely on what we term ‘reflection practice’, a distinctive type of social practice, and that feedback attentive to the particular energy-using practices of householders is likely to have most influence on demand. Neither the smart meter standards nor current commercial devices are found to incorporate these latest research findings, potentially significantly limiting the ability of the UK smart metering programme to fulfil its domestic energy demand reduction objectives.

Keywords: smart meters; feedback; behaviour change; theories of social practice; standards; reflection practice

1. Introduction

The UK energy system is currently undergoing a planned and managed change (via the Smart Meter Implementation Programme, hereafter ‘the SMI Programme’) to incorporate, and integrate, Information and Communication Technology (ICT). The aim of the SMI Programme is to provide the technical capacity to collect, distribute, analyse and make use of fine-grained (small time resolution) electricity and gas use data from domestic properties and selected small business properties in order to assist energy supply and demand management. This involves installation of smart electricity and gas meters in properties, as well as implementing the ICT infrastructure to distribute data to companies managing the energy network. The SMI Programme is being

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*Corresponding author. Email: martin.pullinger@ed.ac.uk driven by the European Union Energy Efficiency (EE) Directive (2012/27/EU, adopted 25 October 2012), but is also part of a wider global process, with similar programmes underway in several countries (notably Australia, USA, South Korea and Japan). The EE Directive was developed to provide increased legislative impetus to meet the EU's '20-20-20 by 2020' targets;[1] the 20% target for reduced energy consumption was projected to be missed (by 10% or half) in the absence of this additional Directive (DG Energy 2011).

The ambitious, consumer-orientated aims of the SMI Programme are encapsulated in the vision developed in the Policy Design stage (July 2010 to March 2011), which was managed by the energy market regulator, Ofgem, on behalf of the UK Government Department for Energy and Climate Change (DECC 2014a):

> The Government's vision is for every home in Great Britain to have smart energy meters, giving people far better information about, and control over, their energy consumption than today. . . . The rollout of smart meters will play an important role in Britain's transition to a low-carbon economy, and help us meet some of the long-term challenges we face in ensuring an affordable, secure and sustainable energy supply. Consumers' interests lie at the heart of the programme. (2011a, 1)

A core aspect of the SMI Programme is its objective of benefiting domestic 'consumers',[2] and small businesses who will, for the first time, all have access to 'real-time' feedback on their energy use via digital devices, notably an 'In-Home Display' (IHD) provided by energy suppliers as part of the smart meter equipment, and optional third-party 'Consumer Access Devices' (CADs), available for purchase by householders. The intention is that these feedback devices – the IHDs and CADs – will enable households to make 'energy saving behaviour change[s]' (DECC 2013e, 25) as a measurable contribution to achieving the aims of the SMI Programme, particularly

- to reduce domestic energy demand, to contribute to national/EU/societal goals to reduce greenhouse gas emissions and ensure 'an affordable, secure and sustainable energy supply' (DECC 2011a, 1);
- to bring direct benefits to householders, notably reduced energy bills 'through a combination of direct energy savings and reduced industry costs and efficiency, which we expect to be passed on to the consumer'; 'qualitative, non-monetised benefits, such as improved prepay experience, quicker and easier switching and better billing arrangements'; '[e]nhanced customer experience of, and engagement with, energy and the energy market'; and 'an end to estimated readings and an improved ability to budget' (DECC 2013e, 21–23).

Given the diverse range of energy market actors involved in the SMI Programme, a central mechanism for coordinating its implementation and ensuring the interoperability of infrastructure and devices has been the development of standards (the Smart Metering Equipment Technical Specifications, 'SMETS') for minimum capabilities of all components, notably smart meters themselves, the 'Home Area Network' which transmits data between devices, and to a more limited extent, the IHDs and CADs provided by energy suppliers.

This paper concentrates on the effectiveness of feedback devices in the UK, assessing the design of current devices that are already available on the market and considering how and why the SMETS standards do not attend to the capabilities of future feedback devices (IHDs and

CADs) in more detail, despite the intention that they play a key role in achieving SMI Programme objectives. Focusing particularly on households, we assess the following core question:

- To what extent do both commercial feedback devices and the SMETS standards enable feedback which is likely to be effective in contributing to householders reducing energy use?

We use the term ‘feedback’ here to refer to any form and medium by which IHDs and CADs may influence householder behaviours, including through presentation of information and provision of features. In this context, we limit the definition of ‘effective’ to the meaning encapsulated in the SMI Programme’s aims, as contributing to householders changing behaviour in ways that reduce energy use.

We draw primarily on theories of social practice as the analytical lens through which to address this question. Such practice theory contributes to understanding how energy is used and how this changes over time by focusing not on energy per se, but on the everyday routines, from space heating and cooling to cooking and washing, through which energy is used, and on the roles of technologies, material environment, skills, social norms and habits in constraining or enabling change (see Section 3). Practice theory is providing insights into the likely effectiveness of feedback devices and the forms of feedback they provide.

The paper is structured as follows: Section 2 outlines the methodology. Section 3 discusses the contribution from practice theory-based research to understanding the effectiveness of different modes of feedback in encouraging change, and its technological and data requirements. This provides the benchmark against which to assess the potential effectiveness of commercial designs, and adequacy of the SMETS standards. Section 4 provides an overview of capabilities of commercially available feedback devices and assesses the possible characteristics of future IHD and CAD designs.

Section 5 provides a detailed documentary analysis of the technical specifications embodied within the SMI Programme, particularly the SMETS standards and how they will stipulate and ‘script’ (Akrich 1992) smart meter feedback device designs and assumed householder usage of them.

In the final discussion (Section 6), we draw on these research findings to explain how the limited inclusion of practice theory insights in the SMETS standards is likely to significantly limit the potential of the SMI Programme to achieve its aim of behaviour change to reduce energy consumption. Section 7 concludes.

2. Methodology

Our research method comprised two main elements: a policy document review and analysis of current commercial feedback devices. First, comprehensive documentation relating to the SMI Programme (available on the UK government website, www.gov.uk, section entitled ‘Policy: Helping households to cut their energy bills’. For URL, see DECC 2014a) was accessed and analysed. Our analysis covers all documents and programme webpages linked to from the following sections of that page:

- ‘How we work with stakeholders’
- All publications
- ‘Further information’

- Consultations relating to technological standards (Functional Requirements and SMETS 2, described in Section 5).

This review of SMI Programme documents was completed during March 2014. The full list of documents selected and analysed is given in this paper's References section – namely all documents authored by DECC.[3]

Second, we reviewed the features and data requirements of current commercially available feedback devices in the UK. Models were selected based on their being rated 70% or higher in Which? Magazine's (print and online), April 2014, review of top UK feedback devices, supplemented with the authors' knowledge of market-leading brands.[4] Products were assessed for the features that a practice theory perspective indicates would enhance their effectiveness (as described in the next section), drawing on product reviews, manufacturers' websites and official user manuals as data sources.

3. Implications of social research for the design of feedback devices in homes

Significant social research on forms of feedback designed to influence domestic energy use has taken place in the last 10–15 years, with substantial investment of government funding from, and prioritisation by, the UK Research Councils (Winskel et al. 2014, 595). This focus on reducing energy use through feedback is itself a part of a wider policy interest in behaviour change and 'demand management' interventions to reduce resource use (notably energy and water), as a 'low regret' form of action where, 'even with uncertainty over the exact outcomes, the overall costs versus benefits are unlikely to be high' (Pullinger et al. 2013a, 496). In part, this is motivated by the observation that only approximately 40% of inter-household variation in the use of gas and electricity can be attributed to pricing, income and socio-demographic characteristics; differences in behaviour account for the remaining 60% (Goddard et al. 2012, 1). This implies substantial potential to reduce environmental impacts through behaviour change.

This renewed interest follows a tradition of feedback research stretching back to the 1970s (Hazas, Friday, and Scott 2011). Recent advances in smart meters, sensors, machine learning and digital displays are rapidly adding new technology-enabled options for monitoring energy use and associated activities, and for designing novel approaches to providing feedback. It is research into these newer ICT-enabled feedback methods that is most relevant to this paper, because it has direct implications for the design of the feedback devices (IHDs and CADs) envisaged in the SMI Programme.

Research on feedback design and effects has drawn primarily on behavioural economics and environmental psychology, but with a notable recent trend towards theories of social practice (Froehlich, Findlater, and Landay 2010; Hazas, Friday, and Scott 2011). Questions remain about whether these approaches – behavioural economics, environmental psychology and practice theory – are ultimately compatible (Hargreaves 2012; Darnton and Horne 2013); we follow the agnostic stance that all three have a value in informing particular aspects of feedback design. However, in this paper, we concentrate primarily on social practice theory, because of the important recent findings which have emerged from this area of scholarship.

It is nevertheless valuable to provide a brief description of feedback design principles derived from behavioural economics and psychology perspectives. Briefly, such feedback typically assumes a user who is a utility-maximising 'micro-resource manager' (Strengers 2011a). Provision of detailed information about energy use, often with associated financial and carbon costs, and comparisons with different time periods or with notionally similar households, is expected to allow users to optimise their energy use to meet their preferences, including environmental values and the desire to fit in with social norms, at minimum financial cost (Strengers 2011a). Empirical research to test such 'information–provision' approaches indicates that these information displays can lead to savings of 5–15% in an average household's energy use; studies of larger scale trials without participant self-selection suggest smaller reductions of 0–5% (Strengers 2013, 74), and there are questions over the durability of reductions over time (Hargreaves, Nye, and Burgess 2010).

New research applying practice theory to analysis of feedback design is significantly less developed, but this alternative analytical lens – used in a rapidly growing body of scholarship – offers a different explanation of how different feedback designs do, or could in theory, influence activities. Practice theory emphasises the need to shift focus from the effects of price signals, income and socio-demographics to the typically everyday and inconspicuous domestic practices which use energy, such as space heating and cooling, washing, doing the laundry and cooking (Shove 2004). It reveals that even in households with similar levels of energy, or water, use and similar socio-demographic characteristics, there is great diversity in terms of the amount of those resources used on particular practices (Medd and Shove 2006). This is because there is considerable diversity in the way in which notionally similar practices are performed in different households: the way in which people wash themselves, for example, varies greatly in frequency, timing, technology (bath, shower, flannel wash, etc.) and location (at home, at the gym or at work). These variations in performance are typically only weakly correlated with socio-demographic characteristics or environmental values (Pullinger et al. 2013a, 501; 2013b, 38–42), and inasmuch as such variations can be expected to influence the amount of energy used, this gives insight into the large degree of 'behavioural' variation in energy use mentioned previously.

Practice theory can be briefly described as follows. A given practice, such as showering, is conceptualised as an abstract 'entity' in its own right (Spurling et al. 2013, 20–21). This entity can be broken down into its 'elements', which both define the practice and act as requirements for its performance. Shove, Pantzar, and Watson (2012) categorise these elements into three classes: materials, competences and meanings[5]: the physical spaces and artefacts; the skills and know-how of the performer; and the meanings they have. The materials, competences and meanings of a particular practice evolve over time, in turn shaped by the wider availability and historical development of different technologies and infrastructure, and cultural and social norms (Hand, Shove, and Southerton 2005). The practices (such as watching TV or reading) and variants (e.g. washing as a weekly bath or a daily shower) which a particular person performs are also shaped and constrained by the availability of the constituent 'elements'. On the one hand, our material environment influences our routines, 'scripting' (Akrich 1992) which practices are possible: the rooms and spaces we inhabit, the technologies in our home, the infrastructure upon which it relies to function and our own bodily capabilities. On the other hand, our competences in performing practices influence what we do: we are more likely to repeat routine activities in the same way because of our embodied, experiential knowledge, typically learnt from those around us. Finally, the meaning of a particular activity, from motivations, emotions and values, to socially informed concepts of 'good' or 'correct' ways of doing, shapes which activities we perform and how we perform them (Shove, Pantzar, and Watson 2012, 22–25). These 'meanings' may include strong commitments to particular values or life goals. However, in line with the 'everydayness' of many practices using energy, practice theory research emphasises the important role of other similarly everyday motivations in shaping how they are performed: the way we control our central heating, or wash, for example, may be most strongly influenced by desires to conform to social norms of convenience or comfort, or levels of cleanliness, or a sense of constraint associated with other responsibilities (Shove 2004).

Crucially, such a theoretical lens indicates that domestic behaviour is not simply based on individual utility maximisation in response to new information. Instead, activities are enmeshed in dynamic, patterned and interconnecting societal practices. This conceptual insight provides practical guidance on the ways in which feedback devices might influence practices, and in identifying the reasons for the limited effectiveness of devices based on information displays.

Such devices are intended to influence practices by virtue of the householder using the device and its features, on a regular basis. From the perspective of practice theory, such use can be interpreted as a separate practice in and of itself – viewing information about one's energy use and how it varies over time or compares with other people's is a distinct activity from the actual practices which result in that energy being used. We describe this as a 'reflection practice', which can be defined as a process of mindfully thinking about how one's routines fit with personal motivations, values and life goals. As with any other practice, a reflection practice may be more or less frequently, habitually and effectively engaged in. This is because it also requires its own materials, competences and meanings for its performance. Such a perspective helps to shed light on the potential role of feedback devices in influencing behaviour. As one of the material elements of such a reflection practice, feedback devices have a twin role:

(1) to enable the reflection practice to be more effectively performed by playing the role of the material element, enabling the householder to find ways to change other practices; and
(2) to encourage householders to engage more frequently and habitually in reflection practice, by making it more meaningful.

In terms of (1), increasing effectiveness, the design of features of the feedback device scripts particular variants of this reflection practice, assuming particular competences and meanings of the performer, and shaping which forms of reflection they can enact. As mentioned above, conventional feedback devices conceptualise the householder as a 'micro-resource manager', who evaluates, based on available information, the most resource efficient way to conduct routines. Whilst householders may in principle be capable of assuming such an identity, this cannot be assumed to be a constant, or predominant, mode of thinking. Indeed, recent research serves to highlight how such a model assumes particular competences of a person that in reality are often only weakly developed: research has highlighted how 'literacy' in the meanings of such energy information, and indeed interest in it, is typically low amongst study participants. Many householders are unsure

(i) what this information means at all (What is a kWh, or a tonne of carbon, and what do these lines on the graph represent?) (Hargreaves, Nye, and Burgess 2010, 6114; Strengers 2011a, 2138)
(ii) what it means in terms of per-appliance/practice energy use and then
(iii) what that means for options for changing practices.

Research has responded to these findings by trying to make energy displays easier to understand, for example, with more advanced and visually appealing graphical elements and natural language descriptions of key information in graphs, and ambient displays (Froehlich, Findlater, and Landay 2010, p. 2004). However, there is also potential to develop feedback which has already undertaken some of the analytical steps implied by (ii) and (iii) (above) that are otherwise left to the householder. Addressing (ii) could include, for example, displaying energy use per appliance and tailoring advice to the households' specific appliances (Ueno et al. 2006; Goddard et al. 2012). This continues, however, to assume a micro-resource manager model of the householder. Addressing (iii) meanwhile implies taking a further step away from behavioural economics towards a focus on supporting reflection on how one's practices match, or fail to match, personal motivations and meanings. This kind of feedback implies a device capable of identifying the practices engaged in by a householder, including their different elements (material, competences and even meanings) and aspects of performance (timings and durations). In line with the aim of supporting reduced energy use, such a device would then identify how much energy each practice uses and derive options for change which fit the household's materials and competences, and meanings conveyed. To the authors' knowledge, there is no research to date which describes or tests options for what such feedback might entail. It is possible to envisage that such feedback could extend beyond practices typically considered 'negotiable' (Strengers 2011b) (such as suggesting shorter, or fewer, showers, or turning the thermostat down one degree), to more significant restructuring of daily routines. This might include changes in practices as diverse as patterns of work, sleeping, engagement in community activities, personal development, visiting parks, rural or coastal places, gardening and socialising. These all have major implications both for the amount and timing of energy used, and for personal well-being and the expression of one's own values and life goals (Pullinger 2014), and are all potentially within the scope of what feedback could seek to influence. Feedback aiming to shift routines in this way might emphasise the benefits of such changes in terms of comfort, convenience and cleanliness, or contribution to personal values. In theory, by being more in line with the meanings which shape everyday practices, this could increase the effectiveness of feedback, compared to focusing purely on financial or carbon savings (Strengers 2013, 91). Feedback devices in this example act as a material element in a reflection practice in which a person considers how their day-to-day lives match with their values – a substantially different reflection practice to that envisaged by behavioural economics as described earlier.

Studies concerned with designing devices to encourage engagement in reflection practices have experimented with a range of approaches, including goal-setting and tracking, comparisons of current and past energy use, social comparisons with others, game techniques (such as incentives or points for particular achievements or behaviours), and exchanging or sharing energy data and commitments to energy reductions with others (see Froehlich, Findlater, and Landay 2010, for a review). These all to some extent seek to encourage frequent performance of reflection by engaging with meanings that the person is assumed to hold around achieving goals, receiving rewards, fitting with social norms, 'keeping up with the Joneses' and sharing ideas out of interest or altruism. It is, however, still unresolved the extent to which such techniques in combination with more practice-based feedback could increase performance of reflection practice, and ultimately increase the level of change in energy-using practices, and energy use, beyond that achieved by the behavioural economics-informed designs described earlier.

In summary, practice theory suggests the limitations of models of feedback devices derived from behavioural economics and environmental psychology: they assume householders have the interest and competences to engage in a resource management style of reflection practice and find ways to adjust energy-using practices accordingly. Practice theory, however, offers a potential way forward, in suggesting that there is scope for feedback devices to support alternative reflection practices in which the relationships between energy-using practices and personal meanings and values, and options for change, given other societal constraints, are explored. However, if feedback devices are to support more reflection on, and conscious interaction with, practices reliant on energy, then this has implications for the design, data-use and technology of feedback devices. For instance, feedback which tailors suggested changes to the particular householder implies a need to identify the practices performed and associated energy used. The technology to achieve this automatically would likely require high-resolution energy use data (such as smart meters could in principle provide) and possibly additional sensor data (such as room temperature, humidity and light levels), as well as advanced probabilistic machine learning methods (Goddard et al. 2012). Furthermore, feedback devices with high-quality displays and significant computing resources will likely be required to select and provide the feedback in a meaningful and engaging format.

The next section reviews the extent to which feedback devices currently available in the UK market enable the types of feedback proposed by practice theory as most effective, in particular whether they have the potential to encourage and support reflection practice.

4. Commercial feedback devices

Analysis here is based on an investigation of seven commercial devices from major suppliers. We draw on practice theory to categorise their characteristics in relation to dimensions of (1) types of information provided (and so the form of reflection practice they assume and script) and (2) encouraging frequent reflection (and thus, ultimately, their theoretical effectiveness in supporting and encouraging the energy saving behaviour changes that are a core objective of the SMI Programme).

Table 1 provides a summary of the prevalence of different features amongst the seven devices.[6] All seven devices present electricity data, collected via sensors clipped onto the main power cable entering the household electricity meter (one device can also collect smart meter data). Only one can present gas usage, as an optional feature requiring an additional clip. Most allow usage to be displayed in kWh, as well as associated financial and carbon costs, with a range of display formats for current usage such as speedometers, and graphs of historical usage over different periods. Most attempt to increase the intelligibility of this information with graphical elements such as smiley faces or pictures of bags of coal, or natural language descriptions.

Few perform the analytical steps from energy data to change in practices as discussed in Section 3. Only one can disaggregate total electricity use (an optional feature requiring extra monitors attached to plug sockets), but only by appliance rather than practice.

In terms of encouraging engagement, different techniques are used, most commonly comparisons: to past usage (in one), to goals (in two) or to other customers' averages (in two). One also has a basic social comparison feature allowing the user to tweet their energy use to a community hashtag; two provide optional smart plug controls, which might serve to increase engagement with the device, by increasing the convenience of controlling appliances.

Whilst six provide a feedback display device of some kind, these are mainly basic; more advanced features, and graphical aids to support intelligibility and engagement present in online web services and apps, are provided by four.

Overall then, there is a significant range of feedback formats. However, they assume a household micro-resource manager using energy, cost and carbon feedback to optimise energy consumption. Disaggregation of energy data by practice and the provision of practice-based advice tailored to the household are uncommon or entirely absent; financial and environmental motivations are targeted, but appeals to comfort, cleanliness, convenience or other possible meanings are excluded.

Table 1. Selected characteristics of seven commercial feedback devices.

(1) *Information provided*	
(i) Household energy use	
• Graphical display	6: Varying levels of complexity of graph, speedometer, smiley houses and other visual aids
• Gas KWh	None
• Electricity KWh	6 (1 online only)
• Financial cost	7
• Carbon cost	5 (2 online only)
• Average usage view	4 (2 online only), over different periods (30 days to 2 years)
• High usage alerts	5: 1 audible alarm; 2 lights; 1 speedometer; 1 by current usage bar
• Language/textual additions	3: natural language comparisons or reports
(ii) Disaggregated energy use	1, via optional smart plugs, by appliance only
(iii) Behavioural/practice advice	5: generic tips; not tailored to the household and their particular practices
(2) *Encouraging engagement*	
Comparisons	4: 2 to other users; 2 to user-set goals/budgets, 1 between years
Social media	1: usage may be tweeted to a custom hashtag
Remote control of appliances and devices	1, via optional smart plugs
Data sources	
Electricity smart meters/meter clip-on sensors	7 Clip-on, 2-15s readings; 1 also smart meter compatible
Other sensors in home	4 Temperature; 1 barometer; 1 optional smart plug monitors; 1 optional gas meter sensor
Other data streams	2 Weather
Display technology	
Dedicated display device	6: varying display qualities; 4 battery powered, 2 mains powered
Web app	4
Phone/tablet app	4
Price	Free (from energy supplier) to £140, mean £64; plus more for optional plug and gas sensors where available

Notes: Figures indicate the number of devices which have each feature. Where information was not available, summary totals assume those models for which the information was missing did not have the feature.

5. Standards in the UK SMI Programme

The SMI Programme has been designed to minimise disruption to the existing market-based energy regime and incumbent actors: existing suppliers are obligated to 'deliver the rollout' of smart meters, including the design or procurement of equipment, with Ofgem continuing its monitoring and regulatory role (DECC 2011a, 2–4). DECC was sole manager of the SMI Programme from inception until September 2013; elements were then contracted out to a newly licenced energy system actor, the Data and Communication Company, which was created to manage data collection, storage and transmission across the UK and to build the required network infrastructure, again regulated by Ofgem (DECC 2011a, 3). Smart DCC Ltd, a wholly owned subsidiary of Capita Plc, was in September 2013 awarded the contract to manage the Data and Communication Company (DECC 2013f, 8).

A key tool for coordinating the Programme delivery across these actors is the set of technical specifications for all data collection, transmission and display technologies both within the home and across the network. First laid out in the 'Functional Requirements' (DECC 2011b), with amendments following a consultation as described in DECC (2011c), these have in turn been converted into more precise technical standards (the SMETS).

Stakeholders have been key throughout the process of developing these standards and other aspects of the SMI Programme via their involvement in working groups. The composition of the SMI Programme board is, however, somewhat misaligned with the Programme's aims (see Section 1), which are heavily focused on the 'consumer', or householder. In contrast, the governance of the SMI Programme has been overwhelmingly producer/utility led: 8 of the 10 primary stakeholders involved are energy companies or energy network associations;[7] the remaining 2 are Ofgem and just 1 consumer rights organisation[8] (DECC 2014a). In addition, despite efforts to consult on the SMETS, only three organisations involved in consumer or citizen interests responded to the consultation: Which?, Consumer Focus and Ofgem (DECC 2013d). In line with the technical nature of the questions asked in the consultation, responses focused on specific technical elements: the accuracy of pricing information to be displayed on IHDs (Which?) and, with respect to CADs, security and ease of access to data for consumers (Consumer Focus, Ofgem). There was only one response from a member of the public. This fits with findings from other studies of standards setting (Bowker and Star 2000; Barry 2004, 2006; Lovell 2014) of its closed, technical and therefore anti-political character: through expertise and the associated use of dense technical language, the development of the SMETS has effectively excluded wider public debate and discussion, in particular by the vital 'consumers'/householders with whom the SMI Programme is ostensibly concerned. This is returned to in the discussion in Section 6.

The rest of this section presents details of the overall configuration of the new UK smart metering system and its timeline, and reviews the content of the SMETS standards. Whilst the SMETS standards are highly technical in subject matter and language, our interest here is in their social processes and implications for householders, in terms of their effect on the capacity of the SMI Programme to deliver reduced emissions and direct benefits to householders via effective feedback. The information presented below on the Programme thus serves to inform the discussion in Section 6 on these issues.

5.1. *The UK smart metering system design and installation timeline*

The envisaged smart metering system design is presented in Figure 1. Data to and from metering equipment will be updated and collected by energy suppliers and network companies, alongside an expected growing range of new third-party products and services (the CADs) (DECC 2013e, 4, 23). Smart meter data will be transmitted via a Communications Hub to the Home Area Network and to the IHD and any connected CADs using the ZigBee transmission protocol, and then to the Wide Area Network (DECC 2013a, 56). The standards in the SMETS for each of these elements, described further below, shape the potential for effective feedback to households.

The current timeline for the programme is summarised in Figure 2. Version 1 of the SMETS was finalised in December 2012 (DECC 2013b, 6). The version of the SMETS standards that will apply to equipment to be installed, SMETS 2, was due for final approval in the third quarter of 2014 (DECC 2013 g, 4), so that the current technical specifications are unlikely to change significantly.

In terms of meter installations, 804,400 'smart-type' meters had been installed in domestic properties by September 2013 – these are apparently for learning purposes, as they are not

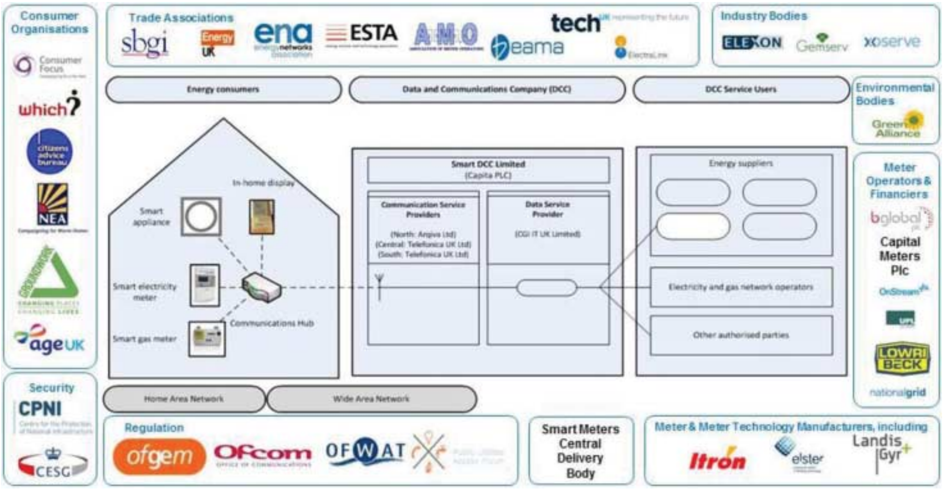

Figure 1. Main components of the smart metering system.
Source: DECC (2013e, 3).

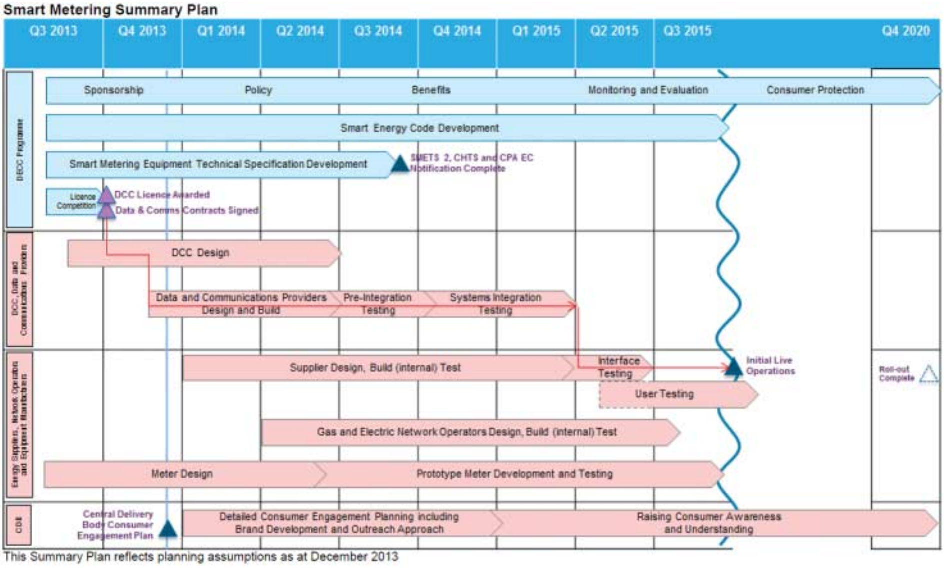

Figure 2. Smart metering summary plan.
Source: DECC (2013g, 4).

SMETS compliant and will need to be replaced by 2020. Some 177,000 smart meters have also been installed – these are able to be made SMETS 2 compliant, but ‘most if not all’ will need to receive updates to achieve this, usually remotely (DECC 2013e, 18–19).

Figure 3 shows the projected further installation of smart meters and advanced meters (for non-domestic properties) from now until 2020. Energy suppliers are responsible for meeting the installation schedule, as well as developing, or procuring, the required technology.

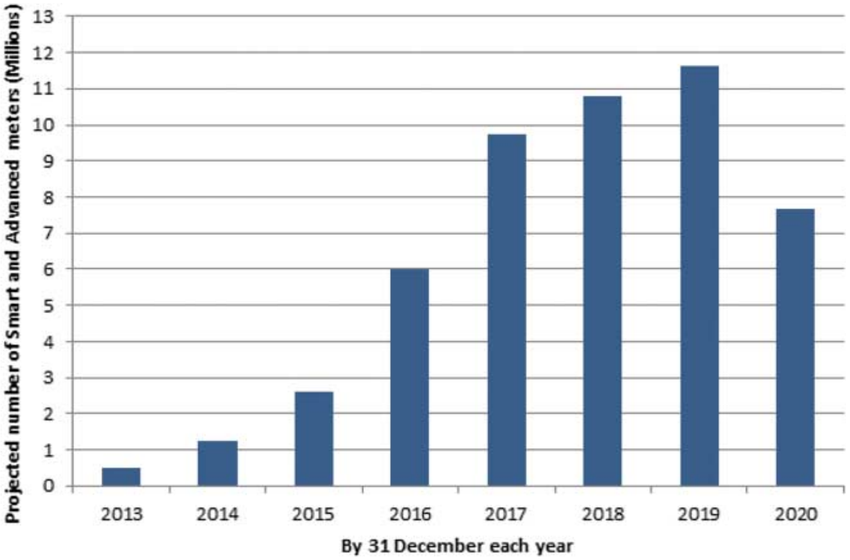

Figure 3. Current projections by the larger suppliers for the number of smart and advanced meters to be installed per annum in domestic and smaller non-domestic properties between 2013 and 2020 (at December 2013).
Source: (DECC 2013e, 20).

5.2. *The SMETS standards*

It is intended that the SMETS will ensure that equipment and infrastructure developed and installed is manufactured to a common level of interoperability. SMETS is described as ‘based on robust, open and non-proprietary standards’, with its non-proprietary nature being intended to control ‘costs over time and [ensure] that smart meters enhance choices for individual consumers’ (DECC 2011a, 2, 23–26).[9] The current latest official draft of SMETS 2 is version 1.57 of July 2014 (see DECC 2014b).

5.2.1. *Data collection, storage and transmission in the home*

As discussed in Section 3, practice-based feedback implies a requirement for high-resolution energy data. The data collection, storage and transmission standards in the SMETS therefore have implications for the potential for commercialisation of such designs. The standards are described below.

SMETS 2 specifies that smart electricity meter data must be transmitted across the Home Area Network at a ‘frequency better than 10 seconds’, with a view to reducing this to 5 seconds in future, ‘when technology improvements are evident’. Gas meter data transmission frequency meanwhile must be at least every 30 minutes, largely due to battery life constraints (as the gas meters will run from battery for safety reasons) – again, this will be subject to future increases in frequency ‘when technology and battery improvements are evident’ (DECC 2011b, Sections 4.45 and 4.46).

Whilst this refers to data being transmitted live, only lower resolution data are stored in the home on a long-term basis for householder access. This represents a compromise between the wishes of consumer groups, market comparison service providers and energy service companies

Table 2. Minimum historic energy use data storage requirements of smart meters under the SMETS 2 standards.

Half hourly data	
Gas consumption	3 months
Electricity	
• Consumption	13 months
• Active energy exported	3 months
• Reactive energy imported	3 months
• Reactive energy exported	3 months
Daily totals, consumption	
Gas	731 days[a]
Electricity	731 days
Other totals, consumption and cost (electricity only)	
Daily	Current day plus prior eight days
Weekly	Current week plus prior five weeks
Monthly	Current month plus prior 13 months

Source: DECC (2014b; for half hourly data: Sections 4.6.5.15 and 9.1.1.61 for gas, 5.7.5.27 for electricity; and for all other data: Sections 5.7.5.12 and 5.7.5.14).

Note: All data stored are date and time stamped, consumption in kWh, cost in £.

[a] Recognising the limitations of the capability of the battery-powered gas meters, this will be stored in the communications hub rather than the smart meter (DECC 2012, 2013a, Section 8).

to have energy use data accessible in the home for CADs, rather than only accessible via web and app interfaces supplied by the energy retailers, and manufacturers' desire to minimise technical complexity and associated costs (DECC 2011b, 10–13). The result is that the highest resolution historic consumption data required to be stored in the smart meters is half hourly, for 3 months for gas and 13 months for electricity. Beyond that, the highest resolution historic energy data stored is daily, going back 24 months (see Table 2 for fuller details). Data must also be transmitted to other devices paired to the meters via the Home Area Network (such as IHDs and CADs) when requested by them (DECC 2014b, Sections 4.5.3.14 and 5.6.3.17). The implications of these data standards are returned to in the discussion in Section 6.

5.2.2. *The treatment of feedback devices in the standards*

A final area of the SMETS which clearly has implications for the effectiveness of feedback relates to the specifications for feedback devices themselves, the IHDs and CADs. Firstly, part of the required package of equipment to be installed by energy suppliers is a SMETS 2-compliant IHD device. This must be mains powered and capable as a minimum of basic display of: the current tariff and payment mode; the current day's, week's and month's cumulative gas and electricity consumption and associated financial cost; the historic consumption and associated cost for the previous week, 4 weeks and 12 months; and, for electricity, the current power usage, the cost of maintaining this for 1 hour and an indicator of whether this is high, medium or low (these are undefined though) (DECC 2014b, Sections 6.2.1, 6.3, 6.4.1 and 6.4.3–6.4.4). The current consumption should be updated at least every 10 seconds for electricity, and every 30 minutes for gas, with a view to increase these to 5 seconds and 15 minutes in future, as technology allows (in line with the smart meter transmission frequencies) (DECC 2011b, Sections 4.45–4.46). Furthermore, SMETS 2 requires that 24 months' worth of daily consumption data must be made available by energy suppliers, 'at the request of the customer', free of charge, to meet the requirements of the EE Directive. This is likely to be via energy suppliers' pre-existing web data access portals for their customers, although there is provision for these data to be made available via the meter interface or by email instead, at the discretion of the energy supplier (DECC 2013a, 70–71).

As a second avenue of diffusion of feedback devices, the SMI Programme also requires energy suppliers to ensure that SMETS 2-compliant third-party CADs are able to access (read only), via the Home Area Network, and free of charge, all ‘consumption, export and tariff information’ both transmitted live and held on the smart meters and communications hub (DECC 2013c, 32, 37). Amongst the conceived possible uses of CADs are to

- ‘display information directly to the consumer (e.g. an enhanced IHD)’;
- ‘ . . . act as a conduit to send data to the cloud (e.g. dongle/router)’;
- ‘ . . . use the information to affect its behaviour (e.g. smart appliances)’ or
- ‘ . . . act as a home energy “hub” which uses consumption and tariff data in combination with non-energy data (such as temperature or information from motion sensors) and consumer preferences (either configurable or “learnt”) to manage energy use throughout the home’ (DECC 2013a, 33–34).

This sets the technical requirements for a new market in CADs, and there is a clear vision for these devices as both deliverers of consumer benefits and drivers of innovation and economic growth:

> A strong uptake of CADs would empower consumers, allowing them to manage their energy use better, and supporting the wider adoption of demand response technologies. A strong market for CADs could also spur innovation across the board; from design and manufacturing to new services, delivering significant benefits to consumers and to the GB economy. (DECC 2013a, 34)

This potentially allows new ICT commercial actors (i.e. from a hitherto separate socio-technical system) to enter this new part of the energy system and provide innovative devices to support behaviour change and other forms of energy management in the home that utilise the new smart meter data.

We turn now to discuss the implications of the latest research into feedback device design for the likely effectiveness of these SMETS standards in supporting reduced domestic energy demand.

6. Discussion

Sections 4 and 5 highlighted that both current commercial designs for feedback devices, and the SMETS 2 standards for IHDs, draw on behavioural economics and psychology perspectives, and replicate models unlikely to achieve substantial and sustained demand reductions. Latest research drawing on practice theory both helps to explain the limited effectiveness of such feedback display designs and provides some theoretical insights into design approaches that might make such devices more effective. In short, such devices are constituted as the material element of a particular variant of ‘reflection practice’, in which a householder is assumed to act as a micro-resource manager (Strengers 2011a), analysing data and then adjusting behaviour accordingly. By failing both to address the often low levels of competence to act in this way and to appeal to values and motivations that would make the reflection practice more meaningful, effectiveness is often limited.

Practice theory suggests that more effective feedback devices would require forms of reflection practice to themselves become more normalised and commonly performed by households. This would involve focusing on increasing the competences of potential performers of the practice, and increasing its meanings, as well as ensuring that devices are designed to constitute effective material elements of it by providing feedback tailored to the energy-using practices of the householder. The extent to which feedback devices could in themselves increase householder engagement in reflection practices is unclear however.

There is scope in principle for both energy supplier-provided IHDs and third-party CADs to provide routes to market and to installation in people's homes for such innovations. However, it seems from the research reviewed in Section 3 that innovations in the design of feedback may require more data than currently specified. The data resolutions transmitted by the smart meters, particularly the gas meters, through the Home Area Network under the SMETS 2 standards are low enough to suggest that additional sensor data may be needed for IHDs/CADs to incorporate practice-based innovations into commercial designs; further research could provide more certainty about this. Extra sensors would, however, mean extra costs and increased visual impact on the home. Further hardware costs are also implied by the fact that the resolution of historic data (daily totals) saved in the HAN under the SMETS 2 standards is certainly too low for disaggregation purposes: any device utilising the higher resolution live data would need to collect and store it in order to have an adequate data set for disaggregation. It does seem feasible, based on the existing market products discussed in Section 4, that a device incorporating such storage hardware and providing feedback via a tablet or computer that the householder is already assumed to own could be produced within the range of £50 or less, but additional sensors could increase this substantially. For CADs, regardless of net benefits, these upfront costs and visual impacts, and low consumer awareness of and interest in paying for feedback devices, particularly if their technology requirements also result in potential privacy and surveillance concerns, represent barriers to future development and widespread uptake of innovative commercial devices. For IHDs meanwhile, the budgetary pressure on energy companies to supply low-cost and long-lasting devices, and the requirement for them to be mains powered (and hence likely fixed in place) put pressure on them to supply IHDs designed to meet only the minimum legal requirements in the SMETS 2 standards to display energy and financial information, and be of limited portability, restricting their practical convenience to the user and hence their usage.

7. Conclusion

This paper considers the pivotal role of standards setting in the SMI Programme, and the prominent role of incumbent actors devising these standards (the SMETS). The SMETS standards have been developed in a largely top-down industry-led process with little input from, or attention to, the householder/'consumer'. As a result, the minimum specifications for IHDs are unlikely to support significant energy and carbon-reducing behaviour changes. The smart meter data resolution now set by the SMETS may also be sub-optimal for development of feedback devices drawing on practice theory design concepts. This finding is in keeping with other studies of standard-setting, where the breadth of expertise found amongst standard-setters is similarly limited, resulting in significant negative implications for outcomes (Barry 2006; Lovell 2014).

Practice theory, however, suggests a number of avenues of innovations that could more fully support the SMI Programme aims, by designing feedback devices that act as the material element of diverse 'reflection practices', including provision of advice tailored to a householder's particular practices and routines. This could be designed to save energy, or encourage shifts in energy-intensive practices away from peak hours, whilst also appealing to the householder's particular motivations.

Empirical data to support these practice theory insights are currently rather limited, but will be informed by ongoing research in the field (e.g. some of the UK Government EPSRC-funded (Build)TEDDI projects[10]). Questions remain about how practice theory can be implemented in device design, and what additional reductions in energy use this could ultimately lead to. The potential to increase performance of reflection practices, by increasing their meaning and supporting competences, and effective ways to achieve that are also open questions – in short, could much greater reflection on intensive consumption of resources be encouraged through other interventions, in turn potentially encouraging the use of feedback devices, and leading to greater changes? The cost effectiveness of reducing emissions through feedback devices, particularly if they require higher resolutions of energy data or further sensors than specified in the SMETS standards, is also an important open question.

Although these standards, as well as wider SMI Programme features, are largely set, there is still scope for policy change to support enhanced diffusion of feedback innovations. Firstly, it may be effective to use the ongoing process of developing the SMETS standards, and the commitment to an open standard, to ensure the results of publicly funded research are incorporated into future iterations of the standards. Future versions of SMETS could include, for example, specific disaggregation algorithms, types of feedback and criteria for tailoring their delivery to households based on their specific practices. Alternatively, it could simply be ensured that such research findings remain open access rather than patented, to encourage their uptake in feedback device designs.

Second, routes to market, and subsequent diffusion pathways (in terms of numbers of houses having systems installed), should be identified for feedback systems that are demonstrated to be cost effective and, if necessary, such routes supported by energy system actors pursuant to meeting the SMI Programme aims. Given that such innovations should contribute to policy goals, such as reducing greenhouse gas emissions, there is a case for government intervention to translate this contribution to macro-level goals into micro-level incentives for companies and householders to, respectively, develop and install such systems. This could include making the development and installation of innovative feedback devices one mechanism by which energy companies can meet the Energy Companies Obligation to reduce domestic energy demand, or allowing their costs to be paid for by consumers using a Green Deal grant or loan.

In summary, practice theory provides us with an alternative, more socially attuned way of understanding how energy is used in homes, and suggests possible avenues – such as greater attention to reflection practice – for increasing the effectiveness of devices designed to influence energy-using practices. As currently configured, the SMETS standards are, however, unlikely to support practice-based forms of feedback device being widely available or used in the near future in the UK.

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Notes

1. Reduce greenhouse gas emissions by 20%, increase the share of renewables to 20% and reduce energy consumption by 20%, by 2020 (DG Energy 2011).

2. In this paper, we follow Warde (2005) in arguing that the concept of the ‘consumer’, as an individual choosing patterns of consumption, is incompatible with theories of social practice, which emphasise the incidental nature of energy and other resource ‘consumption’ as part of everyday activities. In keeping the analytical focus on householders to whom feedback is targeted, we conceptualise them as performers of socially and materially mediated practices. Nevertheless, the term ‘consumer’ is used throughout policy and standards documentation, so we do use it in referring to these documents.
3. From within each of these documents, we included in analysis Executive Summaries, introductions, all general information about programme aims, actors, processes and timelines, and all sections specifically relating to IHDs, other energy supplier-provided channels for householders to access energy data and other forms of feedback, third party CADs, Functional Requirements and the SMETS standard. Given the central role of the SMETS standard to our analysis, the latest publicly available draft version (version 1.57, from July 2014) was included in our final revision to this paper, completed in September 2014.
4. The models selected, in alphabetical order, were Alert Me Smart Energy, British Gas Energy Smart, Eco1 Saveometer PSM 2652, Efergy Elite, Efergy Engage E2 Hub kit, GEO Solo II + hub kit CT clamp and Owl CM160.
5. Whilst different practice theory scholars classify elements in various different ways with differing emphases on their relative importance, this approach – developed by Shove et al. – best explains our empirical findings and offers important conceptual insights.
6. A breakdown for each separate product is available from the authors upon request.
7. E.ON, EDF Energy, Energy Networks Association, Npower, Scottish Power, Southern Electric, First Utility and Utilita.
8. Although this organisation itself was first renamed (from Consumer Focus as stated on DECC’s webpage to Consumer Futures), and then subsequently ceased ‘as a Non-Departmental Public Body’ on 31 March 2014, with its functions being transferred to Citizens Advice, Citizens Advice Scotland and the Consumer Council for Northern Ireland (Consumer Futures 2014).
9. There is also explicit focus on enabling other future developments in smart grid, electric vehicles, energy management and smart water metering (Consumer Futures 2014).
10. For a list, see http://teddinet.org/buildteddi.

Notes on contributors

Dr Martin Pullinger is a Post-Doctoral Research Associate in the School of Informatics, University of Edinburgh, UK. He has a background in understanding how patterns of work and everyday practices influence carbon footprints, energy and water use in the home, as well as well-being, and how options for changing individual practices are shaped and constrained by wider policy and socio-technical systems. His current research focuses on multidisciplinary social science understandings of how ‘behaviour change’ interventions such as digital feedback devices influence practices.

Dr Heather Lovell is a Reader in the School of Geosciences at the University of Edinburgh, UK. She has a first degree in geography and has researched and taught social aspects of climate change and energy for the past 15 years. She has held research positions at Durham and Oxford Universities, the University of Technology (Sydney) and in UK Parliament. Her research to date spans Sociology and Human Geography, and covers two main topics: carbon markets and accounting, and low-energy housing. She has been funded by the UK Research Councils (ESRC, EPSRC), the UK Tyndall Centre and the Nuffield Foundation.

Prof. Janette Webb is Professor of Sociology of Organisations, School of Social and Political Science, University of Edinburgh, UK. Her research, funded by the RC-UK Energy Programme and the Energy Technologies Institute, is about socio-technical innovation in sustainable energy in urban settings. She is a member of the Scottish Government Expert Commission on District Heating. As a member of the Royal Society of Edinburgh multidisciplinary Inquiry: *Facing Up To Climate Change*, she examined the responsibilities of civil society in relation to the sustainable use of resources. She has held research funding from the Economics and Social Research Council, the Engineering and Physical Sciences Research Council, the Energy Technologies Institute, UK Government Department of Energy and Climate Change, Department of Trade and Industry, the Equal Opportunities Commission, British Council and HE Funding Councils and has published widely in social science and management studies.

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