Large-scale testing of new technology: some lessons from the UK smart metering and feedback trials

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Abstract

In 2006, the UK government commissioned the Energy Demand Research Project (EDRP), to assess the potential impact from a range of improved forms of feedback to residential energy users, and to test smart metering technologies. This was against a background of policy with four main objectives: reducing carbon emissions, maintaining security of supply, achieving affordable warmth for all and promoting competitive markets.

Work on the project began the following year, with final results due in 2011. The EDRP has been the most complex set of residential energy experiments conducted in the UK, and probably in the world. Over a period of more than two years, it has involved four major suppliers, over 50,000 'trial' households at the peak, and 10,000 control households. Smart electricity and gas meters were installed in 18,000 of those households, and there have been numerous experiments with billing information, energy efficiency information, real-time display devices and smart meters (alone or in combination). The database includes information on building fabric, heating type and control, customer demographics, and consumption (at hourly or half-hourly intervals for the smart metered households). There is also qualitative information on customer responses to the project and customer-utility relations, along with data on the practical issues faced by meter installers.

This paper, from three members of the external evaluation team for the project, sets out the rationale for the EDRP, and outlines some of the issues confronting those who implemented and evaluated these tests of new technology and communications. The authors draw out some lessons that can be applied in the planning for smart meter rollout, and that are relevant to the conduct of future trials.

Rationale for the EDRP

New technology is typically tested at a small scale before any widespread deployment takes place, and then spreads either slowly or rapidly through local or world markets. Items are bought by individuals or companies. Sometimes, as with the development of the motor car or the mobile phone, infrastructure must be provided in order to support the spread of the technology and meet the demands of users (paved roads, base stations). And sometimes the technology is itself infrastructural. This is the case for utility metering, which is entering a period of major change. Although the idea of 'smart metering' was introduced in the late 1970s, it is only in the last decade that metering-with-ICT has become commercially feasible. Although such metering may be used for electricity, gas, heat and water, much of the attention centres on electricity, because it is there that high-resolution data can contribute most to system management. The eventual aim, for electricity, is to develop 'smart grids'. A smart grid is defined by the European Technology Platform as

> *an electricity network that can intelligently integrate the actions of all users ... generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.*[1]

Smart metering for electricity is an element in managing the smart grid; for gas, heat and water, it is used mostly for remote meter reading, more accurate and timely billing, leakage detection, remote connection and disconnection. There are other functions, such as allowing shifts between credit payment and prepayment, but they do not apply to all new meters. There is no single definition for a smart meter. Advanced metering infrastructures (AMI), and the meters themselves, are commissioned to perform different functions in different contexts – see Darby (2009) for some examples of this.

The business case for an AMI will vary according to the set of problems being addressed in that particular context, although saving on operational costs (primarily the payment of meter readers) is a common factor. In California, Ontario and Victoria, for example, a major objective has been to introduce interval metering to enable time-of-use pricing, and the business case has relied heavily on avoided peak generation. However, peaking is less of a problem in more temperate climates, and business cases for the Netherlands, UK and Ireland have needed to include estimated social and environmental benefits from reduced consumption and carbon emissions. These benefits, the reasoning goes, can be achieved by using improved feedback from the new meters to raise customer awareness and reduce demand. While smart meters are not essential for useful feedback, they can be used in such a way as to provide it, for example through more frequent, accurate billing and through connection with home energy displays. A major cost-benefit analysis carried out for the UK government concluded that 'modelling results show that provision of feedback on energy consumption is very cost effective and can bring significant benefits in a GB plc context', although 'the energy savings and associated peak load reduction and carbon benefits arising from customers' reaction to being provided feedback on their consumption is the most uncertain of all parameters we have modelled' (Dimitropoulos 2007, p88). The analysis set the total net benefit of feedback effects between £3-20 per meter per year, depending on technologies used and the way in which rollout took place (for example, by geographical area, or dispersed over space and time).

These considerations form part of the background to the UK Energy Demand Research Project (EDRP). The invitation to bid for the trials stated that

[1] http://www.smartgrids.eu/?q=node/163, accessed January 2011

> *The purpose of the pilot is to enable Ofgem* [the energy regulator], *central Government and other stakeholders to gather firmer evidence of customer response to improved information on energy consumption through a variety of measures.*
>
> (Ofgem, 2006a)

The project was in fact not so much a pilot (in which a previously-tested technology is tried out in real-life conditions), as a series of experiments, in which various technologies and customer-supplier arrangements were tested in relatively controlled conditions that stopped well short of those for a national rollout. For example, in a national rollout [almost] everyone would be aware that they were part of a new development, discussed publicly and probably backed by public information campaigns.

Each supplier in the project submitted a report every six months to the external evaluation team, led by the Centre for Sustainable Energy, Bristol (CSE). The evaluators reported in confidence to the regulator, Ofgem, the body responsible for overall management of the trials. Ofgem reported in turn to government, and produced a brief public summary report each six months. At the time of writing, the final evaluation of the trials was not quite complete, with the final report expected during the spring of 2011[2]. The aim of this paper is to complement material in that report, giving an account of how the trial was set up, conducted and evaluated, and drawing some provisional conclusions from the process, and from some of the interim findings.

Setting up and evaluating the trials

The invitation to bid for the EDRP was sent out in August 2006 by the director for retail markets and environmental policy at Ofgem. The objectives were to

- *Undertake a series of trials of various approaches to reducing energy demand, including, in particular, feedback mechanisms which provide increased information on energy consumption in order to influence the behaviour of domestic energy consumers.*
- *Evaluate the different approaches so as to identify those methods whcih encourage domestic consumers to become more energy efficient and reduce, on an enduring basis, their energy consumption.*

(Ofgem 2006a, p1)

The expectation was that the both smart electricity and smart gas meters would be included in the trials, along with display units and innovative prepayment meters. There would also be trials of other 'non-smart' methods of encouraging 'energy efficient behaviour', such as historical or comparative feedback information on bills, energy display monitors in conjunction with traditional meters, audits, advice or reward schemes, and schemes involving third parties such as local authorities. The trials were to last for two years, to allow for data collection over two summers and two winters, and also to test the duration of any effect associated with an experimental intervention.

Ofgem was aiming for a 'balanced set of investigations covering, if possible, the full range of options', but did not expect any single trial to cover all options. The Department for Trade and Industry (DTI) contributed £5m (€5.9m) for the purpose of testing out smart meters, while the Department of Environment, Food and Rural Affairs, DEFRA contributed a further £4.75M

[2] Postscript: it was published on June 23rd 2011, and can be found at http://www.ofgem.gov.uk/Sustainability/EDRP/Pages/EDRP.aspx

(€5.6m) to test behavioural interventions more broadly[3]. The initial meeting of prospective bidders, the government departments then responsible (the), and the regulator Ofgem (who would manage the trials) took place in September 2006, to discuss some of the complexities.

Asked by prospective bidders whether they were looking for ease of use by customers, the regulator replied that 'consumer interaction is vital ... The focus is on the domestic sector but, as was mentioned in the bid letter, we can see the potential for some overlap to, particularly, SMEs' (Ofgem 2006b). The government and regulator were looking primarily at customer response in terms of changed overall demand, but were also interested in gaining information on the potential for load shifting. They wanted to find out more about both *individual* experimental elements or 'interventions' (e.g. smart meters, improved billing, real-time displays, and energy advice) and *combinations* of these. They were interested in any differential impacts on sectors of the population, particularly those in fuel poverty (ibid.). All of these issues were to be considered in terms of guidance for a national rollout of smart metering. For evaluation, it would also be necessary to have metadata on nature and size of trial groups, on sampling techniques and on the exact nature of interventions. The significance of the metadata became particularly clear during the later stages of the evaluation.

Twenty-two organisations bid to undertake the work, and were evaluated against the criteria of

- Total value of government funds requested and amount of private funding being contributed (at least 50%)[4]
- What was to be explored, and how this fitted in with the wider pilot in Great Britain
- Ability to carry out the trials to timetable and within budget, including demonstration of technical understanding and expertise
- Statistical soundness of trial design and sample size
- Reliable and appropriate access to customers' energy consumption information.

(Ofgem 2006a)

Four of the major energy retailers were selected: EdF Energy Customers plc (EdF), E.ON UK plc (E.ON), Scottish and Southern Energy Supply Limited (SSE), and Scottish Power Energy Retail Limited (SP). The trials took place in a changing policy environment, in parallel with two public consultations on the functionality and implementation of smart metering. At the start of the trials, the government had made no commitment to national adoption of any form of smart metering, but the passage of the Climate Change Act in November 2008 paved the way for it, and the new coalition government confirmed the decision to roll out smart metering when they took office in May 2010 – that is, well in advance of the final results from the trials.

It is worth noting that these results cannot give 'the answer' on public response to a new technology in the home. Instead, they show a *range* of outcomes following a large number of experiments with utility-customer communications, energy consumption feedback in different forms, and different types of meters, bills, other communications and real-time energy displays.

The trials also show a process of learning and development taking place: 'experiment' is probably a more accurate term than 'trial'. Arguably, many of the interventions were not high quality. The suppliers were learning as they went along – simplifying their letters to customers,

[3] Responsibility later transferred to the new Department for Energy and Climate Change, DECC
[4] The Government contribution amounted to £5m via the Department of Trade and Industry, plus £4.75 via the Department of Environment, Food and Rural Affairs

for example, or learning how best to enable a Local Area Network in an apartment block. The feedback display devices were mostly ‘first generation’, while the TV and web packages were in process of development. The suppliers were trying to get their products and processes to work well and acceptably for the customers at the same time as they were testing for effects, and it is important to read the findings in this way. A comparison with the phases of clinical trials might be instructive.

In 2006, any future rollout was seen as most likely to be carried out by the retailers (with whom the customers have a relationship, but who are widely seen as having an interest in selling energy, not saving it), and not by the network operators (almost invisible to the average customer, but with no interest in selling kWh, and a particular interest in load management). For that reason, there was value in building up knowledge and practical experience of smart metering in the energy retail industry.

As the objectives and criteria cited above show, the tendering was carried out according to a loose specification, and led to a series of trials that were under the control of suppliers/retailers, with no coordinated research leadership. A Standard Reporting Framework was in place at the outset (see below), which was developed and improved over time, but it did not provide a solid basis at the outset for comparisons between the various experiments. While this loose specification meant that the suppliers had an opportunity to explore options for a process which they were likely to be implementing in the future (smart meter rollout), it also set the scene for many difficulties in interpreting the trial data.

There was a separate bidding process to select external evaluators for the trials, following which a team led by the Centre for Sustainable Energy at Bristol (CSE) was appointed. This comprised CSE staff, with expertise in sustainable energy implementation, community energy programmes and policy analysis, plus academic and technical advisers. The six-monthly reports to this team were each followed by interviews in which at least two of the evaluators discussed findings with each supplier’s project team, in person or over the phone. This process worked fairly well, although the lack of overall research design showed up as a fundamental problem as soon as the first findings were reported, leading to a revision of the Standard Reporting Framework. Reports were of variable quality and tended to be lengthy, partly due to the shortage of time in which to digest and edit the material, but the interviews gave an opportunity for the evaluators to clarify meanings and discuss any issues with the suppliers.

Additional help was sought towards the end of the trials, primarily from statisticians, to assist with the complexities of making sense of data and metadata. A second evaluation team led by AECOM was brought in during the final stages, following a tendering process, to analyse overall impact, including ‘rating and weighting’ the quality of each trial and making a careful analysis of the metadata, in order to put the trial findings in perspective.

Figure 1 shows the relationships between those carrying out the trials, the evaluators, and those they reported to. It indicates how the evaluators acted as a filter between the diverse approaches of each trial (and of each academic/statistical advisor), and the programme manager, Ofgem. The statistical advisory teams to each supplier were each dealing with a trial over which they had no control, while the suppliers were in relatively new territory in conducting such large-scale and complex trials.

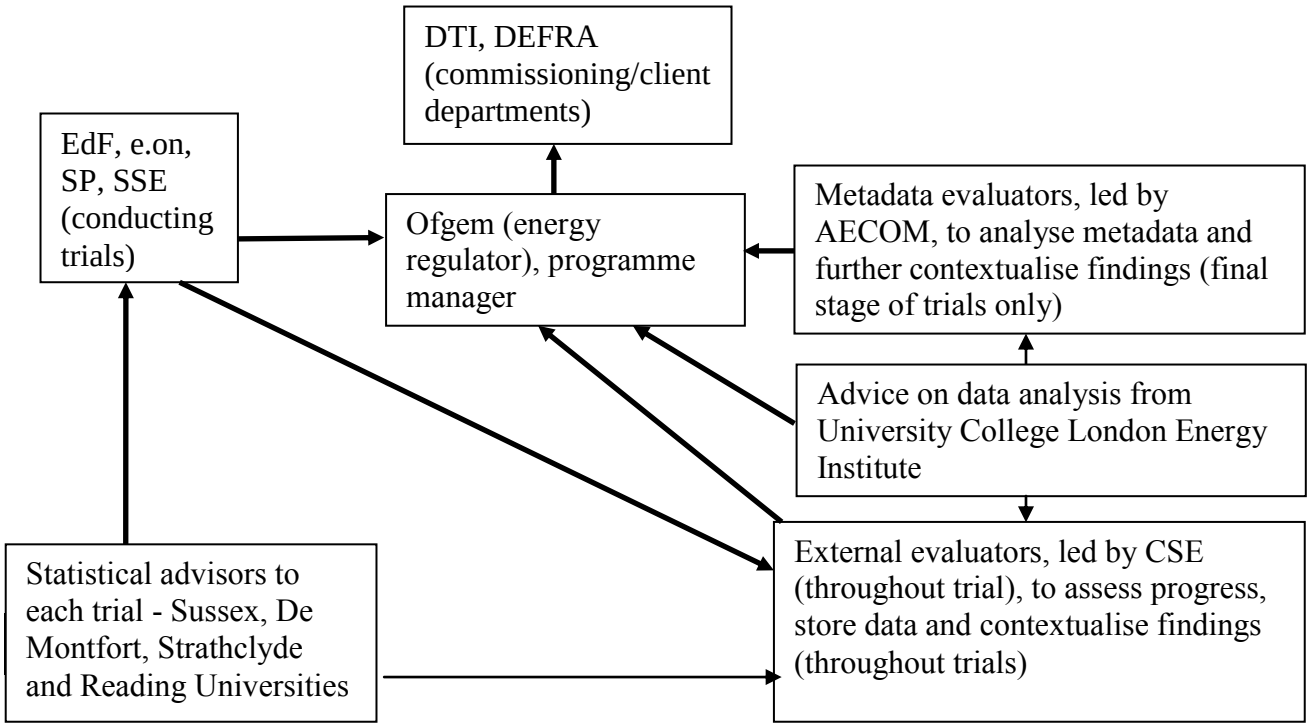

Figure 1: principal reporting relationships (bold lines) and other communications during the EDRP trials

The overall structure of the research project is summarised in Figure 2. The figure of 60,000+ households includes approximately 17,000 in control groups. Although the trials are sometimes referred to as 'smart metering trials', smart meters were installed in only around 18,000 of the homes, with or without other interventions. Most trial households did not therefore receive a smart meter, but participated in tests of informative billing, written energy information or advice, real-time electricity displays, or other non-smart intervention.

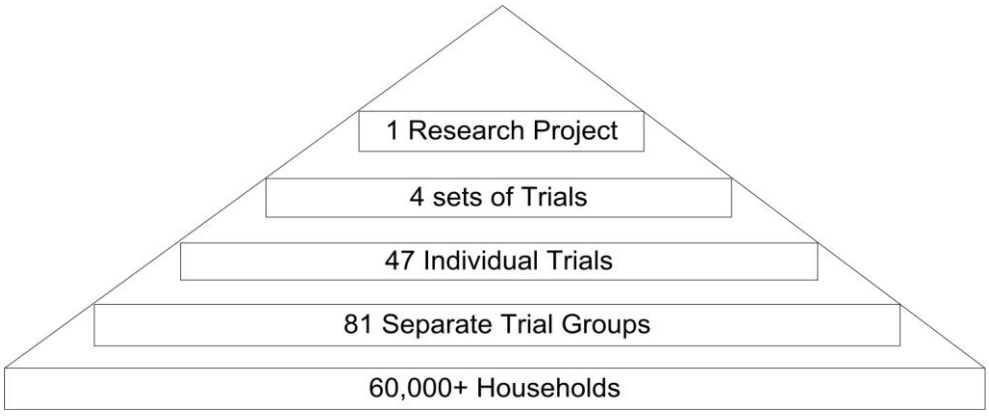

Figure 2: Structure and scale of the Project (from Ofgem/CSE, Standard Reporting Framework)

The four trials

There were two large trials (e.on with approximately 17,000 households, SSE with approx. 23,000, and two smaller trials (EdF with 2,000 and SP with 1800).

Each supplier took a separate approach to the research. EdF issued *all* participants with smart meters, and tested different technologies for displaying energy information, such as wall panels with and without heating controls, written material, TV, and a website. Scottish Power adopted a sequential approach, adding interventions over time. The two larger trials were both multi-factorial: e.on took a particular interest in responses from different demographic groups, while the SSE trial involved no fewer than 83 trial groups, each with its own combination of demographic or consumption characteristics plus intervention (or combination of interventions). SSE also set up three community trials, in which the members of a village or urban community adopted an energy-saving challenge and were offered support in meeting it plus monitoring at substation level.

The trials were scheduled to begin in the summer of 2007 but there were some delays due to technical issues. Most trials began in late 2007/early 2008, and the final trial ended late in 2010.

Reporting framework, evaluation, data collection, storage and analysis

Ofgem established a Standard Reporting Framework (SRF), in order that the reported data could be organised consistently to assist comparison within and between trials. All trial teams were required to use this and all did, after some initial difficulties with compliance. The framework included a system for identifying trial groups, structure and content of reports, and approaches to aspects of sampling, data management and classification.

At the outset, there was no plan to collect data centrally, but this has proved to be critical given the need for independent analysis and the likely long-term interest in using the EDRP dataset for other analyses. All data are now anonymised, stored by the CSE, and are to be made available at the end of the trials, although arrangements are not finalised at the time of writing.

The trial evaluators structured each of their six-monthly reports to Ofgem according to the SRF, in terms of

a. Overview
b. Trial details: the nature of each set of interventions being analysed, and of each group of households involved, including those that had left the trial.
c. The scale and nature of the effect of each set of interventions on domestic energy consumption, in absolute terms, and relative to control groups (including indirect impacts of electricity-focused interventions on gas consumption and vice-versa). This proved extremely difficult in most cases, because of the large amount of statistical ‘noise’ and also because of difficulties in establishing comparability between the many different samples and subsamples.
d. Practical issues: customer service and response, technical issues during trial setup and during trials. Actual versus expected costs (final report only)
e. The suitability of each set of interventions for large scale rollout (final report only)

The most basic data consist of metering data, both from ‘dumb’ meters and ‘smart’ interval meters which provided half-hourly figures for electricity and hourly figures for gas. The quantitative data also included installations attempted and completed, equipment performance

and acceptance, demographics, and customer segmentation. Consumption data therefore had to be categorised in relation to technologies used, household demographics, and type of interventions employed. Choosing the algorithms with which to weather-correct consumption figures proved a lengthy process.

Issues arising during the trials

Analysis posed a major challenge to suppliers. As shown above, these were exceptionally complex as well as exceptionally large-scale trials, with each taking a different approach to sampling, timing, customer relations and technologies. Each supplier subcontracted analysis to academic statisticians (three from the start, one later in the process). Both suppliers and academics showed great commitment to the trials, but were hampered from the outset by the fragmented design-by-default. Each academic team had its own approach and priorities, but little or no control over trial design.

Qualitative data included surveys of customer reactions and some records of customer contacts with supplier's customer services. However, there was no consistent approach to the surveys across the trials, and survey design quality was highly variable. Two suppliers (SSE, E.ON) used a validated energy survey, while the other two left survey design to market research companies. Again, this stood in the way of cross-trial comparisons, although an attempt was made to produce a common final customer survey, in consultation with all the trial managers. Collection of other qualitative data was somewhat opportunistic, ranging from focus groups to the highly-detailed (anonymised) records of customer comments and complaints kept by SSE.

Many of these differences impeded the analysis, but some highlighted important issues for rollout. As an example of the latter, EdF Energy, who installed smart meters in all of their trial households, were meticulous in seeking written permission from all customers before they did so and had great difficulty in recruiting; they eventually gained more recruits by promising them accurate bills in place of estimated bills. In contrast, SP simply installed smart meters on the basis that they were 'business as usual' replacements. (This has been the procedure in Sweden and Italy, among others.) These experiences can inform the debate as to whether a smart metering rollout should be publicised with major media attention – as was the case with TV digital switchover in the UK – or be carried out in a low-key manner.

In the early stages of the trials, the main issues related to recruitment, and to technical and practical difficulties in installing the new smart meters and getting communications to work properly. Installation of the gas meters was particularly fraught with practical problems. Aligning new data with utilities' legacy billing systems was a persistent issue for the trial managers.

Customer segmentation raised issues of definition. Some categories (e.g. geographic) were straightforward. Others caused problems, e.g., definitions of fuel poverty based on postcode data only; or the definition of 'high consumers'. One supplier segmented customers in such a way that categories overlapped and it was not possible to present any results for 'all households'; two defined 'high use' groups for analysis, although consumption data from these households would inevitably be confounded by regression to the mean. The highly complex multi-factorial design adopted by SSE made it very difficult to pick up the likely small effects of single or multiple interventions above the normal high variability in household energy consumption (the statistical 'noise'). Combining multiple interventions makes the identification of intervention-specific effects even harder.

The main single issue, then, related to sampling and experimental design. It soon became clear that comparability across trials would be difficult, given that the competitive tendering process had resulted in four separately-managed studies with no mechanism for comparison across them. The tendering process also handed control of the trials to energy companies who, although they had academic partners to assist them, were running experiments without the experience to understand the potential risks to data quality and utility. This became evident in the approaches taken to recruitment, where initial sampling plans were replaced with more opportunistic approaches when difficulties arose, thereby compromising the results. Another example is the linear design of the SP trial, and the addition of interventions while the trial was in progress in order to test out customer responses. These made thorough assessment of the effects of any single intervention impossible.

Some interim findings

The final report on customer response is due during 2011 (see footnote 2 above), and this is no substitute for that report. But it is worth pointing out a few of the interim findings from the trials, as noted in progress reports issued by Ofgem. The difficulties described above, while serious, do not mean that there are no valid and useful findings from the trials. A number of practical and procedural lessons have been learned or reinforced through carrying out the trials and fed into the policy discussions and consultations on rollout[5]. In addition to what suppliers have learned from their individual customer surveys, interim findings included the following:

- While most practical difficulties with meter installation were easy to spot and treat, some were not recognised until the meters and communications interfaces had been installed for some time. Occasionally a potential installation had to be halted.

- Installers needed training for the installation of the smart meters; they also needed 'softer' skills to explain the new technology to customers. (Alternatively, other people need to carry out the explanations.) And customer advice line staff needed time to learn about the new technologies and procedures in order to be able to answer customer queries.

- Experience with clip-on display devices (in conjunction with traditional meters) was mixed, in terms of installation, technical and consumer issues. The trial uncovered problems with battery failure and replacement, installation and understanding, which were fed into the debate on smart metering implementation (Ofgem 2008). A separate exploration of customer preferences for home energy displays was carried out by Anderson and White (2009) during the period of the trials.

- Two of the three communities taking part in the trials achieved their goals of 10% reductions in gas and electricity consumption. They demonstrated the value of social learning, community leadership, a hands-on approach to technology adoption and advice, and the impact of a valued incentive (in this case, a substantial cash prize). However, the two successful communities were organised and committed to an energy-saving initiative before the start of the trials. While this points to the significance of 'context' or preparedness in producing particular outcomes, these communities demonstrate what is possible, but cannot be taken as representative.

[5] See detailed supporting documents for the 2010 public consultation supplied by Ofgem and DECC, at http://www.decc.gov.uk/en/content/cms/consultations/smart_mtr_imp/smart_mtr_imp.aspx .

- In keeping with other research on understanding of energy information (e.g. Anderson and White 2009), customer responses showed that they typically understood and appreciated information presented in money terms rather than in kWh or carbon units.

- Also in keeping with other research, there was no consistent energy saving impact across the many interventions involving different forms of real-time feedback, reinforcing the message that 'a focus on technology alone is unlikely to have a major effect on consumption and that other action to engage and motivate consumers will be required' (Ofgem 2010, p6).

- Interventions without smart meters did not result in energy savings, while some interventions with a smart meter did result in savings, suggesting that smart meters can be 'a vehicle for effective action to reduce domestic energy demand' (ibid.). (Note: a more exact account of findings on energy savings will be given in the final report of the EDRP.)

- There were considerable difficulties in developing TV-based energy displays, and problems with setting up websites, followed by very slight customer interest in the sites.

- Indications were that financial incentives to save energy were only effective for as long as they lasted, in line with the research literature (Darby 2010).

Summary: lessons for future trials

The Energy Demand Research Project (EDRP) was intended to assess the potential impact from a range of improved forms of feedback to residential energy users, in connection with the assessment of potential benefits from an advanced metering infrastructure. If it could be demonstrated that smart metering enabled customers to reduce their consumption in a sustained way, then the social and environmental benefits would add to the operational benefits anticipated from an AMI. The experiments also set out to test different metering and communication technologies, differential responses due to demographics and consumption levels, and a community engagement strategy.

The trials began in the autumn of 2007, with the last trial ending in the autumn of 2010. They took place at a time when policy on smart metering was already developing, so the full findings and lessons have not been available to inform policy development during this period. However, the trials have done a good deal to inform suppliers, government and other stakeholders about the many practical and consumer issues connected with a large-scale rollout of smart metering technologies. They have helped to focus attention on the degree of customer support needed for a successful rollout, the arguments for and against 'geographical' rollout in particular areas at a given time, on customer requirements for feedback and the best way to meet them, and on the practicalities of installation and the reorganisation of billing systems.

The main single lesson to emerge is the need for very clear definition of the purpose of large-scale trials or experiments with new technologies, allied with a design to meet that purpose. In these trials, the wish for a strong science-based outcome from government combined with the wish for better understanding of their customers from the energy retailers, and the combination did not always work well in terms of clear results. Although the suppliers were in an excellent position to reach the thousands of householders who took part in the experiments, and put great

effort into the project, they were not experienced in carrying out research on this scale, and their academic support was fragmented.

The EDRP is in some respects a cautionary tale for those contemplating large-scale trials. As shown above, it involved an extremely complex set of experiments, many involving new technologies, carried out by a large number of actors who were operating in unfamiliar territory. Difficulties were to be expected. For all those taking part – the energy retailers who planned and operated the trials, their academic advisors and industry partners, the evaluators, some of the participants and Ofgem itself – there was a great deal to learn about what happens when retailers try to introduce new technologies into their business systems, and to develop new arrangements with their customers. With hindsight it can be seen that, while the suppliers could still have contributed their own proposals for interventions at the tendering stage, the actual specification of the trials and their conduct should have been at cross-project level. It soon became clear that the experiments were producing a more disjointed set of findings than had been intended; the disparate sampling and operational strategies have led to great difficulties in trying to make statistical sense of the data. The EDRP experience illustrates the importance of 'metadata' in contributing to the outcome of an experiment or trial, and the significance of overall research design and leadership in producing a coherent set of results.

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