Demand response and smart technology in theory and practice: customer experiences and system actors

Sarah J. Darby

Energy Programme

Environmental Change Institute, University of Oxford

http://www.eci.ox.ac.uk/research/energy/index.php

OUCE, South Parks Road, Oxford, OX1 3QY, UK

sarah.darby@ouce.ox.ac.uk

Abstract

Energy transitions change the relationships between technologies and human actors. Demand response (DR), the matching of demand to available electricity supply, is a relatively new activity, important for systems that rely on distributed renewable generation. Price-based DR is spreading among residential and small business customers, along with direct control of distributed and aggregated small loads, mostly thermal. In both types of DR, information and communication technology plays a part.

This paper contributes to the debates on implementing electricity system transition and on adoption of smart technologies. Through analysis of a large-scale demonstration of highly-distributed smart thermal storage in three European countries, using mixed methods, it supports the claim that DR can usefully be seen as an outcome of interactions between technologies, activities and service expectations. Adopting a broad scope of enquiry to take in customer experiences of DR and the contributions from a range of actors, the paper shows how it was possible to achieve useful levels of aggregated DR in some circumstances. The quality and quantity of DR were influenced by customer experiences of taking part in the demonstration, which in turn were affected by three types of communication: connectivity, control and care. Outcomes also depended on contributions from a range of actors, especially the 'middle actors' who had some direct contact with both customers and programme leaders.

Mainstream theory of DR has concentrated on deploying technologies, controls and price signals. The paper demonstrates how, in practice, effectiveness relates to social and organisational as well as technical and economic features of energy systems. It

concludes with some implications for design and implementation of DR programmes, and for smart energy policy in general.

Keywords

smart energy; demand response; thermal storage; customer experience; user engagement; middle actors

1. Introduction: the nature of energy transitions

Energy transition is typically thought of in terms of changes in sources of supply (Leach 1992; Pachauri and Jiang, 2008) and technological breakthroughs (e.g. Chapman and Itaoka, 2018). with much of the vocabulary drawn from physics, engineering and economics. For example, at the time of writing, one search engine's 'top ten' responses to the term 'energy transition' referred to decarbonisation, increased electrification, renewable energy, low carbon, energy efficiency, clean energy, carbon-free electricity and pumped-hydro storage.

Yet it is clear to any interested person that changes in the energy scene go beyond abstract concepts and physical objects: they affect livelihoods, commercial relationships and everyday activities. Bridge et al. (2013) also add an important dimension to our understanding of transitions by analysing them as processes that are shaped by geography. In doing so, they add important terms to the transition vocabulary, such as location, landscape, scaling and spatial embeddedness. By taking human as well as physical geography into account, Bridge et al. also point to the significance of political decisions at different levels in shaping energy systems and influencing the ways in which systems are operated, regulated and governed: for example, whether they are centralised or distributed, integrated with other systems or stand-alone, accepted or resisted by operators and citizens, equitable or discriminatory in their impacts.

If space is an important factor in energy systems, then there is a strong case for describing and analysing at different spatial scales; and if transitions are social and political as well as technological, then it makes sense to include these in analyses, in order to enrich and develop our understanding of current systems and future possibilities. The literature is starting to broaden out in this direction (e.g. Moss et al., 2015; Darby, 2017; Köhrsen, 2018). Such studies show how it is realistic and practical to think of energy systems and subsystems in '360^{o}' terms, taking into account not only their physical characteristics but also their operational infrastructures, actors and resources, and the relations between these.

Information and communication technology (ICT), or 'smart' technology, is seen as a crucial element of new electricity systems and is an example of technological change that involves new actors, along with altered physical and legal infrastructures. Professionals have to be trained to incorporate new equipment and processes into their work, while 'lay' customers/citizens may also need to adopt new practices. More broadly, an energy transition involves new coalitions of materials and people, new forms of knowledge and skill, and new forms of activity. Demand response, adjusting the demand for electricity to match available supply, offers an example of combined physical, social and relational changes in the course of energy transition.

The aim of this paper is to present and analyse some findings from a large-scale demonstration project to test a novel form of DR via a highly-distributed technology – smart residential thermal storage – in three European countries. A mix of qualitative and quantitative methods was adopted and carried out with the aid of project partners and participants over a period of 2.5 years. While some of the findings are specific to smart thermal storage, most offer more general lessons about how to implementsmart energy initiatives effectively.

The paper is structured as follows: an introduction to demand response in general terms (2) is followed by a section in which DR potential from highly-distributed loads is discussed (2.1); both draw on literature review. Section 3 sets out the background to the demonstration project and outlines the methods used. Results are summarised and discussed in sections 4 and 5; section 6 broadens out the discussion and draws conclusions for policymakers, practitioners and academics.

2. The growth of demand response

A shift from centralised electricity generating plants towards highly-distributed and renewable sources is also a shift from demand-led to supply-led systems. Put another way, it is a shift from systems in which relatively flexible supply (from thermal or large hydro plants) adjusts to demand, to systems in which supply (increasingly from sun and wind) becomes less flexible and demand must be matched with what is available. System efficiency becomes as important as component efficiency and flexibility becomes something that has to be worked for, if it cannot be provided simply by turning thermal generators up or down (Grünewald and Diakonova, 2018).

Demand response (DR) – an 'active demand' response to changes in available supply– is therefore increasingly important as a way of adapting to distributed renewable generation (e.g. Bouffard and Kirschen, 2008; Darby and McKenna, 2013). It highlights electricity system features that have previously been less obvious, such as activities and expectations that shape the scale and timing of demand, and the extent to which these activities and expectations can be altered and shifted in time. Interruptible contracts between suppliers and large industrial customers have long been a way of responding to unexpected peaks in demand, along with standby generators, but the focus has shifted over the last 10-15 years towards load-shifting and load reduction by commercial and residential customers, requiring some changes in practice (Torriti et al., 2010; Grünewald and Torriti, 2013). Such customers are gradually taking on some system-balancing functions that traditionally belonged to the supply side so that, for example, increase in 'peaking plant' capacity is replaced by regular load-shifting away from peak times, and continuous balancing of power output in response to system frequency change is replaced by frequency control on the demand side via automated load control (Darby, Strömbäck and Wilks, 2013). We see the growth of price-based DR, which extends DR to residential and small business customers (although without giving them access to balancing or most capacity markets) (SEDC 2015); there has also been an increase in quantity-based DR: direct control of highly-distributed loads by demand aggregators. Most of these loads are thermal, which may be able to offer access to balancing and capacity markets (Darby 2018). Electric vehicle charging is an obvious candidate for direct load control and/or time-varying tariffs (Schuller et al., 2015.

In order to move beyond manual load-shifting in response to network stress at predictable times of day, both price- and quantity-based DR require ICT support. This can take the form of services such as two-way near-real-time communications on demand, network conditions and prices; optimisation engines and their interfaces with suppliers, customers and grid; and remote-control arrangements. Sophisticated smart technology is not essential for all forms of demand response but some form of ICT typically goes hand-in-hand with DR development.

A supply-led system is one where the role of electricity customers has to be rethought. Whereas users have in the past simply paid for a service *from* the system (to enable activities or improve comfort), they may now find themselves supplying services *to* the system through distributed generation, demand response and storage. So relationships between system elements and actors are changing: energy transitions involve far more than simply connecting new sources of supply into networks and grids (e.g. Sauter and Watson, 2007; Wolsink, 2012; Eyre et al., 2018).

A review of nine major smart-enabled demand response and efficiency programmes carried out by VaasaETT (2012) illustrates how good customer relations can build trust and improve effectiveness. Prompt, reliable customer service is likely to be the primary key to trust-building but communications in general are crucial: customers are in effect taking part in a 'journey', as new equipment, arrangements and tariffs become available, and the authors of the review argued that *'If we are to obtain the interest and involvement of consumers and avoid the patronising feel that typically characterises utility-consumer relationships, then consumers must be able to learn at their own pace, in their own way, to their own desired extent.'* (ibid., p.2). Utilities can assist this, for example by maintaining or strengthening customer feedback. If carried out well, this can boost the effectiveness of both demand response and conservation programmes (Faruqui and Sergici, 2013). Darby et al. (2015) offer a detailed account of the positive role of user feedback and customer support in the British smart meter rollout programme (which, unusually, offers an in-home display (IHD) to each customer. The Code of Practice also requires installers to be trained to explain how to use it and to give basic energy advice).[1] A further study from VaasaETT (2019) draws on data from 578 customer engagement pilots to develop the evidence base on the value of feedback (ideally, from several sources, with the IHD as the single most effective source) in achieving energy and bill savings and increasing involvement in DR programmes. Interestingly, the analysis also shows that home automation alone tends to increase rather than decrease consumption, leaving customers as passive, unaware elements in the system.

Each DR programme is set up for particular purposes and operates within physical and regulatory constraints. It also operates according to what actors are willing and able to do. Electricity users own or use a range of resources – buildings, equipment, vehicles, skills – that may be suited to DR. They also belong to social networks and take part in activities that influence their demand patterns and may also affect decisions on whether to invest in distributed supply and storage. For example, there may be financial benefits from DR in the workplace, or from setting up community co-operatives to raise money to pay for generation assets (Boait et al., 2019); or from building up new knowledge, practical skills and social capital that can be put to use in order to meet requirements in a specific place (Ornetzeder and Rohracher, 2006).

To summarise, DR is a work in progress, something that has to be reconfigured as technologies, activities and requirements evolve. It relies on a range of physical and human resources and the feedback loops between these will influence effectiveness.

[1] An update on consumption by customers with smart meters (plus, normally, in-home displays) and legacy-metered customers, showing the former group using approximately 3% less gas and electricity than the latter, is in Table 2 of the House of Commons Committee on Science and Technology Committee's evidence check of the smart metering programme https://publications.parliament.uk/pa/cm201617/cmselect/cmsctech/161/161.pdf (accessed July 2019).

2.1 Conceptualising highly-distributed DR potential: limitations and possibilities

There is considerable DR potential from highly-distributed loads: for example, UK households account for ~30% of overall electricity demand and ~50% of peak demand. But distributed DR processes and outcomes are more complex and less easy to predict than those from interruptible supply contracts with large-scale customers, for reasons that have to do with space, time, customer service expectations and activities. For example,

- technologies that play a major part in transitions from centralised to distributed electricity systems, notably electric vehicles (EVs), heat pumps and solar photovoltaics (PV), are typically clustered in neighbourhoods where housing types, demographics and social influences are favourable (Darby and McKenna, 2012). Their demand and generation patterns will therefore have a greater impact on local distribution networks than on the transmission grid: it can cause severe problems if, say, clouds cause major fluctuations in a large number of PV panels connected to a single substation, or if many electric vehicles in a street are charging rapidly at the same time. Tariffs designed to support the grid may not be best suited to local needs, and vice versa.
- Different types of demand, such as consumer electronics, EV charging, food refrigeration and lighting, change in varying ways as social practices, technologies and regulations evolve. For example, ICT usage changes as people discover new applications for the Internet, while people adopt EVs when they see attractive, affordable vehicles, along with the infrastructure for charging.

- Some loads are simply inflexible because of the activities they represent, such as regular business activities, cooking or watching a big sporting event. Some are more flexible but still subject to variable daily choices about activity and urgency, e.g. clothes-washing or electric vehicle charging. Relatively inflexible loads can be particularly significant for local network operators and can also have implications for greenhouse gas emissions (Torriti et al., 2015)
- Thermal loads (cold appliances, water heating, electric storage heating, heat pumps and air-conditioning) are relatively suitable for direct/ remote control because they are switched on continuously or for relatively long periods and because they may be switched off for short periods without inconveniencing customers, especially in well-insulated buildings. However, thermal loads contribute to a service – thermal comfort – that people see as extremely important and usually wish to have some control over. Indeed, the ability to control can itself contribute to a sense of well-being and comfort; put another way, reduced control through over-mechanisation or automation has been shown to reduce comfort and satisfaction (Steemers and Manchanda, 2010).

Electrical loads in homes and workplaces, especially thermal loads, thus offer the promise of substantial demand response but there is a risk of alienating occupants if their comfort is affected, making them less likely to participate in DR programmes. There is clearly more at stake here than price and technological capability and, given the significance of demand response in energy transitions, we need a more comprehensive and practical theoretical grounding from which to develop our understanding of how DR might best develop.

McKenna et al. argue (2018) that residential demand response potential is usefully conceptualised as a product of technologies, activities and service expectations. A similar argument could be made for commercial DR. The figure below illustrates demand response potential as a three-dimensional space, showing how the full potential is only realised through changes in technology, energy service expectations and the ability of users to carry out demand-related activities in more or less system-friendly ways.

[Fig 1]

From the diagram, we see that flexibility can be seen in terms of

- physical characteristics. For example, what is the power rating of an appliance? Can it be switched on and off easily, manually or remotely? Which appliances are suited to direct load control (DLC)? What regulatory and safety conditions must they comply with? While we have some quantitative and qualitative evidence on how people use technologies in DR programmes, it is still quite patchy, with a great deal based on the single end-use of air-conditioning.
- energy service requirements. For example, how much will people want to load-shift or have some devices controlled remotely? How much heating will they require: what temperatures, at what times? How many laundry washes a week, at what temperatures?
- users' activities and in their ability and willingness to loadshift. What are customers' activity patterns each day and how regular are these? Do they know

how to operate their controls effectively for DR? Do they trust the supplier/load aggregator?[2]

Implementing widespread DR – developing an electricity system so that more flexible DR becomes possible – involves uncertainties along the same dimensions but on a broader scale. A power system can no longer be viewed simply as a set of generating plants linked by wires to each other and to (largely undifferentiated) 'load' . It also includes electricity users, touch points with other systems such as gas, heat, transport and water; data and digital platforms; system and market regulations; business models and contracts. [3] The technologies have to be used by people who are able and willing to take part in DR (activity); they are designed for particular purposes and operate within physical and regulatory constraints (service expectation).

All this points to a need to widen our ideas about demand response to include more of the human and organisational dimensions, and to develop more empirical evidence of what is possible and how it can be achieved. Some assumptions about DR are questionable, e.g. assumed 'economically rational' behaviour among customers, and the extent to which operators know what is going on within their systems. Yet lack of practical experience and empirical data can still send modellers back to these flawed assumptions and it is reasonably seen as a major challenge facing demand response (O'Connell et al, 2014), highlighting the need to use new tools in designing demand response and then interpretresponders' experiences: tools that take us beyond engineering and economics. Through more qualitative work, for example, we are starting

[2] Trust in suppliers being a crucial factor in acceptance of direct load control (Fell et al., 2015).
[3] For an example of how this thinking has been applied, see https://es.catapult.org.uk/wp-content/uploads/2018/11/FPSA3-Fast-Track-to-Britain's-Future-Power-System.pdf

to learn something about DR and smart grids as technical *and* social phenomena, and to plan for a broader range of measures and actors in implementing smart technologies (Pallesen and Jenle, 2018; Boait et al., 2019).

3. Developing a theoretical understanding of demand response through empirical study: background to the smart thermal storage demonstration

As an application of the three-dimensional, 360° concept of DR to an empirical study, this paper draws upon material from a project, 'RealValue'[4], that set out to demonstrate the viability of two technologies (residential electric storage heaters and electric hot water cylinders). These were ICT-enabled to offer fully-flexible charging to network and grid managers, rather than simply charging during night-time hours, as had traditionally been the case. The demonstration project lasted three years, with smart electric thermal storage installed in ~800 premises (mostly homes) in three European countries (Germany, Ireland and Latvia), each with their distinctive climates, networks, regulatory and built environments and social characteristics. Note that, in most of these premises, the new heaters were replacements for older, less efficient and non-smart models; the people who used them were therefore used to the concept of storage heating but had to adjust to the more efficient heaters with their digital controls.

The project involved setting up and testing complex configurations of organisations, people, devices, software and business models in commercial and operational conditions that were as close as possible to those that they might experience in real life in the near future. The word 'configurations' is important: the researchers were not only evaluating

[4] https://cordis.europa.eu/project/id/646116

single items such as heaters, smart meters, sensors, gateways between networks, customer controls and aggregator software, but combinations that could allow heaters to charge flexibly at any time of day when supply was abundant, while meeting customers' needs for warmth and hot water. That is, the customers were to set the parameters within which the system could benefit from flexible charging, by programming their space- and water-heaters with temperature and timing requirements. The value chain ran from householders through aggregators and manufacturers to system operators, raising the question: could there be enough value in flexibility to ensure that everyone in that chain would benefit from demand response?

The project was large and complex, set up on the hypothesis that small-scale thermal storage, optimised with the aid of ICT, could bring benefits to energy market participants throughout the European Union. Here, the paper draws on material from the consumer impact study, which set out to answer the question 'Can smart electric thermal storage work for both customers and grids?' (Darby et al., 2018). This study took a broadly practice-theoretical approach along the lines set out by Gram-Hanssen (2010) in which the following were seen as important topics of inquiry:

- customers' *understanding* of their heaters and hot water cylinders. and of the DR programme as a whole;
- their *ability* to take part by adapting their service expectations, learning new forms of control and altering the relationship with their supplier;
- the *rules and conditions* under which the DP project operated in each country – the national regulatory context;

- the *meanings* that different actors in the project gave to DR, from customers through to strategic planners. These were considered important in relation to the services or value that people were expecting, and what they were willing to do in order to bring about effective DR;
- the *technologies* involved and their connectedness with each other and with the human actors.

Note how this approach relates to the conceptualisation of DR in Figure 1: it takes into account customers' service expectations, their activities and the technologies involved. The approach also considers other actors in the DR programme: this enables a more complete analysis of an interactive web of people and technologies.

Some characteristics of the project were of particular interest with regard to smart energy policy and practice:

Scope for distributed, smart-enabled demand response in the European Union

In some countries with winter-peaking electricity demand, storage heating is a highly significant load and a significant provider of intra-day storage services, using power overnight to heat high-density bricks to a high temperature and discharging the heat gradually throughout the day. Prior to the project, storage potential in the EU from smart-enabled replacements of residential storage heaters and hot water cylinders had been estimated at almost four times that in dedicated storage capacity (primarily pumped hydro), with up to 51GW of controllable demand by 2050 projected across the EU (DNV KEMA, 2013). While continued growth of storage heating (a type of direct resistance heating) might not be desirable, there was thought to be considerable scope to upgrade existing heaters in the short to medium term. Heat pumps have the advantage of being considerably more efficient than resistance heating in most circumstances and may also be used for smart-enabled storage/demand response; some of the processes and actors analysed in the study are relevant to situations involving heat pumps.

Contrasting environments for demand response

There is not space in this paper to offer details of the context in which each trial took, but there was a basic analysis of the background conditions in Ireland, German and Latvia that helped with interpretation of the empirical findings. As examples, the German householder participants mostly lived in owner-occupied family homes, relatively well-insulated, while the Irish participants were more likely to be tenants in social housing apartments; there was widespread public support for Latvian energy independence and German energy transition, whereas in Ireland energy issues were not much discussed except in the context of fuel poverty; Ireland had a high and growing proportion of wind generation in the electricity mix, whereas Latvia was highly dependent on hydropower. For more detail, see Darby et al., 2018.

Development of dynamic pricing

Pricing that reflects the cost of provision at a given time is an important element in making demand response commercially viable, though it calls for careful testing and regulation and is slow to emerge. Historically, customers with storage heating had typically been on a simple day/night tariff, with cheap electricity overnight and sometimes for a few set offpeak hours during the daytime. They were therefore familiar with the basic concept of static time-of-use pricing, but fully-flexible demand response and dynamic, cost-reflective pricing were unfamiliar.

Distribution of DR assets, actors and processes

Storage heating is unusual as a network resource because the utilities who stand to benefit from the storage do not usually invest in it: the highly-distributed assets are owned by the people who use them, or by their landlords. The demand aggregator, and the system as a whole, therefore have to rely on the willingness of asset owners to put their devices at the service of the system; they are obliged to offer terms and conditions that will make this sort of arrangement viable.

Control of assets

Management of the heating appliances was shared between utilities/demand aggregators and customers. Customers had traditionally adjusted basic analogue controls on the heaters to switch off, reduce input or output, and 'boost' heating if necessary during the day, but the heaters had been charged up overnight by grid or network operators, by some form of remote control. For the new generation of smart-enabled storage heaters, control was still shared but the possibilities and complexity were enlarged.

3.1 Putting smart thermal storage into practice: methods used to analyse customer experience and interactions leading to demand response

The project was a demonstration of a socio-technical process (demand response) in complex real-life conditions with a very large number of variables. As such, it did not lend itself to an experimental approach; rather, the aim was to carry out a realist-type evaluation (Pawson and Tilley, 1997) in order to assess what worked, for whom, and in what conditions. The 'social' researchers assigned to the project aimed to capture and analyse customers' experiences of preparing for, and then taking part in, a new demand response initiative. Beyond that, they also aimed to describe and analyse the human and technological interactions, to serve as a guide to understanding and implementing smart grid initiatives in more general terms.

The project required a combination of quantitative and qualitative research in order to evaluate how effectively the smart thermal storage was working for end-users and for the electricity system. Where the social dimension was concerned, the emphasis was on qualitative enquiry and the main activities were

- an assessment of the national contexts for DR in each country, including the regulatory context (the 'rules').
- surveys of over 260 customers carried out at or around installation, about midway through the three-year project and towards the end; that is, over a period of roughly 2.5 years.
- focus groups with customers and some of the equipment installers/ heating engineers; these were carried out mid-project.
- semi-structured in-home interviews with 70 customers, carried out midway through the project or towards the end.
- semi-structured phone interviews with a range of project partners, including those responsible for leading the project in their respective countries, towards the end of the project.

Where possible, quantitative data was included, for example to establish whether customers in Germany were making savings in their energy bills by taking part in demand response.

Conduct of the surveys

There were three rounds of surveys in the course of the project:

– A 'sign-up' survey before the new appliances (or, in some cases, retrofit gateways for old appliances) were installed. The aim was to collect baseline information on topics including demographics, household occupancy (including pets), the fabric of the home, heating history, sense of comfort, expenditure on electricity, how much control people felt they had over their heating and whether they were aware of time-of-use tariffs.

– A post-installation survey. Within two months of installation, this was to check whether the process had gone well, pick up any early problems with the technology and assess customers' satisfaction with their ability to control their appliances and the level of support received.

– A final survey, as close to the end of the project as possible, to assess general satisfaction levels, what advice had been most helpful, confidence in controlling heaters and cylinders, perceived changes in behaviour, electricity bills and comfort levels; and thoughts about demand response, variable tariffs, and the customer engagement arrangements during the project.

The surveys were structured, with an 'open' question at the end of each for respondents to add any thoughts or queries.

Tables 1 and 2 summarise these arrangements, which had to be carried out in order to fit with other project work in each country at the time.

[Tables 1 and 2]

All surveys and interviews were carried out in the respondent's native language. The interviews, like the focus groups, were semi-structured and designed to go into customer experience in greater depth than was possible with the surveys. With the help of a NVivo software package, the survey data, interview and focus group audio records and transcripts, photos and observation data were organised and cross-checked in order to make comparisons between countries, identify themes emerging from the qualitative data and use them to build up a picture of customer experiences as a whole. Further details are given in Darby et al. (2018).

The findings presented here come from customers who completed at least two surveys, (see Table 2), as their data was the most complete. The survey findings below are supplemented by observations of project processes and some material from interviews carried out with customers in their homes and with project partners.

4. Findings: customers and their experiences of smart thermal storage

The hypothesis underlying the demonstration project was that small-scale thermal storage, optimised with the aid of ICT, could bring benefits to energy market participants throughout the European Union. The demonstration project partners found that setting up novel arrangements for demand response through smart thermal storage was not always straightforward. It took over two years to meet the aim of fully-flexible charging (that is, 24-hour demand response capability) using two-thirds of the available thermal load. The hypothesis was therefore supported in general terms (and there have since been some moves to incorporate smart thermal storage in commercial DR programmes).

Along the way, valuable lessons were learned about regulatory arrangements, physical network conditions and software quality, all of which posed challenges at times. The research into customer engagement gave valuable insights into the scale and type of effort that went into recruiting and retaining customers who were willing and able to operate their space- and water-heating to provide demand response, while the qualitative research into customer experience offers a guide to programme design: what is needed to develop and maintain DR from residential or small business customers.

Recruitment

Roughly a third of respondents in all three countries were over the age of 65, a slightly higher proportion than in Europe overall, and 43% were retired, with 9% unemployed. The gender balance was almost equal; most households were small, with approximately 40% having only one occupant and almost as many having two. Reported income levels varied quite widely; it is worth noting that very few of the Irish respondents answered the question about income and home visit observations indicated that many were on low incomes. 8% of survey respondents reported income levels below, or on the 'at risk of poverty' threshold for their countries and this will have been an underestimate. Communication with customers, and their experiences in general, were highly relevant to the smart thermal storage demonstrations in Germany, Ireland and Latvia. Without customers who were willing to enrol in the DR programme and satisfied with participating, there would be no demand response. Great care was taken to recruit participants, and then to develop and maintain good communications with them; this was an important factor in the programme's effectiveness as a whole.

Customer experience and readiness to take part in demand response

When the researchers came to evaluate customer experiences through surveys, interviews, and focus groups, they found that most of the participating customers took a positive view of demand response in principle, provided it would not stand in the way of affordable, reliable heating. Five themes (detailed in Darby et al, 2018), emerged as contributory factors to a good customer experience. They were

1. *Comfort*. This was the single most obvious consideration when customers were asked about their new and more efficient smart-enabled equipment and their brief experiences of taking part in fully-flexible demand response. Comfort is a highly-subjective concept and we did not attempt to measure it quantitatively, beyond establishing that thermostat set-points ranged from 16-24^{o}C in the Latvian and from 21-23^{o}C in the German households, while in the Irish participant households the average was 21 ^{o}C but a significant minority or customers had setpoints of over 24 ^{o}C when visited in their homes (Darby et al., 2018).

   For the most part, customers stated that they were more comfortable with their new heaters than previously (when most of them had had less efficient and less attractive devices, with relatively poor controls). Comfort was influenced partly by customers' ability to control their heating (see below), partly by the type of housing and how well-insulated it was, and partly by the technology itself. For example, in the German trial, the smart storage heaters were charged using an algorithm that took into account current outdoor temperatures and the weather forecast for the area; this worked well. In Latvia, where there could be dramatic changes in temperature from day to day, customers sometimes had difficulty keeping warm with their new heaters.

2. *Cost*. Retail costs for the new heaters ranged from €575-1793 in 2017, depending on size, while the new water cylinders (advertised as long-life and low-maintenance) were, at ~€1100, slightly more expensive than standard models. However, the project supplied new heaters and cylinders to customers free of charge.

Running costs were a concern, though: customers could reasonably expect to make savings over standard resistance heating or less-efficient storage heating, by benefiting from the use of offpeak, lower-cost electricity. However, they was not as great a concern as had been expected. Cost is often seen as the main or only consideration when planning or modelling demand response and, at the start of the project, the surveys showed that customers' main expectation was that they would save money on their energy bills. But towards the end of the project, 58% of 132 customers surveyed – including many on low incomes – judged cost to be of roughly equal significance with comfort, while a further22% considered comfort to be more important than cost.

Overall satisfaction with the equipment was high, with three quarters of a sample of 161 customers in all three countries saying they were satisfied (35%) or very satisfied (39%). Yet only one third of 75 customers surveyed on the topic (who had all previously been accustomed to storage heating) thought they had saved money on their electricity bills as a result of taking part in the project, while half estimated that their bills had stayed the same as previously.[5]

The other three themes all relate to communication and are of special interest when considering the 'smart' nature of the project. Some project partners had hypothesised that, ultimately, all smart thermal storage could be managed through technology alone. However, the data on customer experience pointed in another direction, showing how smartness/intelligence is distributed between technology and humans.

3. *Connectivity* (communicating between technologies). This was one of the most problematic issues for the project. Even if separate hardware and software components of a DR system are market-ready, there is no guarantee that they will work in connection with other elements. Project partners had to invest considerable effort in getting all devices connected up to enable flexible charging. In general terms, the more complex the connectivity arrangements are, the higher the risk of malfunction, for example when software is upgraded or a component manufacturer goes out of business. Customers understandably wanted their heating to be fully reliable and some had been unsettled by a disruption when there was a software upgrade that caused over-heating in Germany and halted charging in Ireland.

4. *Control* (communicating between people and technologies). Customers needed to be able to alter appliance settings, directly or remotely through an app, to

[5] Unfortunately it was not possible to check this via billing data for all customers. However, there was some data from the German trial to show that customers who used their equipment and controls as intended by the project designers were making savings on their bills.

manage their comfort and keep costs within acceptable limits. They also had to move from analogue to more sophisticated digital controls. This was not a problem for some but proved difficult for others. The customers were offered face-to-face advice and written information during installation (and sometimes afterwards), and participant surveys showed that 75 out of 161 respondents (46%) claimed they were altering the controls sometimes, while a further 30% stated that they knew how to do so, which indicated a fair degree of confidence. However, in-home interviews showed that some of this apparent confidence was misplaced, with some misunderstandings of the controls and a substantial minority of interviewees who rarely if ever altered settings, sometimes because they were afraid of disrupting their heating. This was more of an issue with older householders, who were less likely to be familiar with digital controls. Interestingly, customers without a good sense of control were more likely to think that their bills had increased during the project than those who were more confident in their ability to control their heating.

5. *Care* (communication between people). Installers, utility call centre staff and locally-based people such as housing managers or knowledgeable neighbours turned out to be important guides to achieving affordable comfort and demand response. Customers particularly appreciated the efforts made by installers and others to explain the new equipment and the idea of flexible charging to them; this often had to be done in stages over a period of time, so that they could get used to their new equipment. Checks by project personnel a few weeks after installation provided evidence of what could be done to improve customer

satisfaction and demand response potential. One significant issue, for example, was the need to make sure that participants did not switch off their heaters at the wall or disconnect their gateways, rendering their equipment unavailable for demand response and 'invisible' to the project. Telephone helplines set up for the project were of some help to customers, but they could not always explain a problem in terms that the adviser could understand, and advisers were not always in a position to help without being able to see what the difficulty was.

The researchers identified 'care champions' who were especially valuable in guiding customers: people who were relatively well-informed and who were known and trusted by participants. Because of their local knowledge and ability to communicate in simple, non-technical language, they could assist in ways that a specialist was not always able to do. One example was a housing manager who was contacted by a tenant worried by high bills: in a misplaced attempt to economise, she had set her heater thermostats low and was then using the 'boost' function every evening (at peak time, when costs were high), in order to stay warm. The housing manager, who had herself learned about the new heating by talking with the project's installers, was able to identify the problem and save the tenant from losing any more money.

These findings on the significance of communication in setting up demand response programmes illustrate how energy demand, like learning, is always 'situated and social', even when much of the control is automated. Local circumstances and communication matter, and local knowledge and personal contact will always have a role to play, especially in the early stages of technology adoption.

The themes identified above lead to questions about the communicators and other actors: who are the people who need to act in achieving acceptable comfort, cost, connectivity, control and care; and what do they do?

5. Findings: actors who implement demand response

The attempt to set up DR and offer value to customers, system operators and third parties through small-scale smart thermal storage was complex and time-consuming, as is usually the case for demonstration projects even when they are relatively small-scale and local. This one had thirteen research and commercial partners in five countries and it involved customers in over 800 premises in three of those countries. It took over two years to meet the aim of fully-flexible charging (that is, 24-hour demand response capability) using two-thirds of the available thermal load. It became clear that the people who contributed actions and decisions that enabled demand response (or, in some cases, stood in the way of it), were as crucial to the success of the project as the technologies they mobilised.

Table 3 below shows actors who were identified in the course of the project as people who regularly or occasionally assisted with mobilising DR. Those in italic can be described as 'middle actors': people with an understanding of the system who are in contact with both customers and strategic actors (Parag and Janda, 2014). Middle actors are able to be effective because they have both agency (the ability to make decisions) and capacity (the ability to act on those decisions). Other actors may be more constrained: for example, many customers have capacity to act, by operating their devices, but not much agency in the system as a whole, whereas senior personnel in manufacturing companies or utilities may have decision-making power but little capacity to implement those decisions.

[Table 3]

This is not an exhaustive list. For example, the utility call-centre staff might themselves have to call on further actors to assist with customer issues, such as the heating appliance manufacturer, or the gateway or broadband provider.

The complexity of a demand response programme is inevitably linked to questions of value: the DR service has to be of high enough value to justify recruiting the necessary equipment and actors. There will inevitably be pressure to keep the number of actors to a minimum. The project experience, though, points to the crucial role played by middle actors in 'oiling the wheels' of the programme so that DR became possible, troubleshooting any difficulties and offering a satisfactory customer experience. Minimising investment in communications could well be a false economy, especially in the early stages of technology rollout; one senior industry partner stated that they would like to allocate 30% of funding for technology demonstration projects to customer engagement (Darby et al., p.68). Another partner, a middle actor, commented on the limitations of remote control/ automation and the need to complement technology with human intelligence and the opportunity to learn from on another: *'All ideas about the remote control have the same difficulty. The communication problem. So, all these ideas for smart: city, smart homes, and so on, have (as) the weakest point the communication.… to make this control we need this communication.'* (ibid., p.31).

This brief account of actors involved in making DR happen is relevant when considering the ethics of DSM. All electricity users have an interest in a reliable, affordable system and if DR becomes essential in order for this to happen, the costs and effort involved in achieving it need to be spread fairly, especially if some of the customers who provide DR through their devices and actions are disadvantaged financially or in some other way. The RealValue participants were safeguarded against financial loss from taking part in the project and had relatively high levels of customer support, but mainstream, commercial DR will need to establish procedures for consent to adopt technologies and tariffs and to allow for any remote control, as well as for providing customer support and taking responsibility for any failures in service provision.

The range of actors is also significant when considering possible business models. Value generated by DR has to be sufficient to allow for all actors to benefit in some way. If, as early experience shows, more actors are needed to produce effective DR than expected, at least in the initial stages, then this has to be allowed for.

6. General discussion, conclusions and policy implications

Smart grid trials around the world are testing end-use and connective technologies in a range of real-life conditions, and demand response from highly-distributed devices in homes and small businesses is becoming a reality, something that can be evaluated in both quantitative and qualitative terms.

in this paper, demand response (DR) has been conceptualised as an outcome of interactions between technologies, activities and service expectations, while smart energy systems have been seen as the product of technologies and human actions and decisions – as socio-technical systems. The findings from the demonstration project with smart thermal storage challenge some received wisdom on the conditions for effective DR. They show that is is necessary to broaden the scope of enquiry from the usual technical and economic considerations in order to include customer experiences of demand response and the actors who make DR happen in specific contexts. Without good customer experiences, there will not be volunteers for DR; and without an effective coalition of actors, the potential for DR will not be realised.

The demonstration project offered valuable lessons on the significance of the regulatory and physical environment in a given location, on technical connectivity and potential business models. It also showed, though the study of customer experience and the roles of actors in a smart technology rollout in three European countries , how customer engagement in demand response is about more than making an attractive financial offer. Operational and transactional aspects of DR turned out to be highly significant. Whereas a typical smart grid diagram shows technologies connected by wires and signals, without any mention of human actors, this real-life smart grid project soon demonstrated many varied roles for humans in operationalising DR. These actors could work at strategic level (acting 'top down'), or they could be householders and business employees who operate switches, set programmers and pay bills ('bottom up). Or they could be the crucial 'middle actors' who have some understanding of the system and are in contact with both customers and higher-level strategic actors (Parag and Janda, 2014).

Put another way, the project findings demonstrated that effective smart systems emerge when smartness is effectively distributed between technologies and people. DR involves customers' judgements on energy services and activities, ability to control equipment (because, even with direct/remote load control, there will normally be manual overrides), a good customer-utility relationship and carefully-judged, agreed rules. It is not realistic to see it as a self-regulating, wholly-automated, fit-and-forget process. There is therefore a strong case for greater policy and academic focus on social innovation and human-technology interactions when designing and deploying energy technologies with the aim of moving to low-carbon and highly-distributed electricity systems (Eyre et al., 2018).

Once the role of human actors in smart systems is more fully appreciated, it becomes clearer to identify materials, actors, interactions, risks and uncertainties that most need attention when trying to develop functional, responsive, supply-led grids and networks. Once identified, these considerations can be built into planning and evaluation of smart grid initiatives. The smart electric thermal storage demonstrations, outlined above, show the significance of good customer experience in recruiting and retaining electricity users who are willing and able to offer DR. They also highlight the number and range of actors involved in turning an abstraction – DR – into a viable service, and they show how the DR only became viable fully when a triplet of system connections was in place: reliable *connectivity* between devices, intelligible human-technology interfaces and *controls*, and constructive person-to-person conversations (*care*). Mainstream, commercial DR requires attention on all these three fronts, with agreed procedures for consent to adopt technologies and tariffs and to allow for any remote control, as well as for providing customer support and taking responsibility for failures in service provision.

Many disciplines are relevant to the study of energy systems and this paper has aimed to show how the study of demand response needs to expand beyond the ‘usual suspects’ among disciplines – engineering, economics and psychology – in order to take into account more of the socio-technical complexities on the ground. Anyone who has worked in smart energy development for any length of time will be familiar with the mismatches between predicted and actual outcomes, theory and practice, models and the realities they attempt to reflect. These differences can only be lessened by paying close attention to how demand response works in practice for the actors involved, drawing on qualitative as well as quantitative data from a range of sources.

For policymakers and those who commission and fund research, the paper highlights the importance of paying attention to the specifics of energy demand, human activity and system infrastructure. When commissioning research or evaluating funding proposals, there is a need to factor in the time, effort and money needed to allow for effective engagement with all participants in a project, in order for learning to take place at all levels. There is also a need to encourage partners (especially those in industry) to allow publication of 'negative findings'. Energy transition is a research area where the stakes are high and we cannot afford to keep making the same mistakes. Demonstration projects are inherently risky, but the risk can be more than compensated for by the learning outcomes if both positive and negative findings are made available and respected. Where smart energy research in general is concerned, there is still plenty of work to be done in rebalancing our framing and analysis of smart systems to humanise them, paying careful attention to the actors involved, the nature and distribution of costs and benefits in different business models, and the development of more productive and equitable interactions between people and technologies.

References

Boait, P., Snape, J.R., Hamilton, J., Morris, R. and Darby, S. (2019) The Practice and Potential of Renewable Energy Localisation: Results from a UK Field Trial. *Sustainability 11*

Bouffard, F. and Kirschen, D.S. (2008) Centralised and distributed electricity systems. *Energy Policy* 36, 4504-4508

Bridge, G., Bouzarovski, S., Bradshaw, M. and Eyre, N. (2013) Geographies of energy transition: Space, place and the low-carbon economy. *Energy Policy* 53, 331-340

Burlinson A. and Giulietti M. (2017) Non-traditional business models for city-scale energy storage: evidence from UK case studies. *Economia e Politica Industriale* 45 (2), 215-242

Chapman, A.J. and Itaoka, K. (2018) Energy transition to a future low-carbon energy society in Japan's liberalizing electricity market: Precedents, policies and factors of successful transition. *Renewable and Sustainable Energy Reviews* 81, 2019-2027

Darby, SJ and McKenna, E (2012) Social implications of residential demand response in cool temperate climates. *Energy Policy* **49**, 759-769

Darby, S.J., Strömbäck, J. and Wilks, M. (2013) Potential carbon impacts of smart grid development in six European countries. *Energy Efficiency* **6**, 725–739

Darby, S.J., Liddell, C., Hills, D. and Drabble, D. (2015) Smart Metering Early Learning Project: synthesis report. For the Department of Energy and Climate Change, London https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/407568/8_Synthesis_FINAL_25feb15.pdf

Darby, S.J. (2017) Coal fires, steel houses and the man in the moon: local experiences of energy transition. *Energy Research and Social Science* **31**, 120-127

Darby, S.J. (2018) Smart electric storage heating and potential for residential demand response. *Energy Efficiency* 11(1), 67-77

Darby, S.J., Higginson, S., Topouzi, M., Goodhew, J. and Reiss, S. (2018) *Getting the balance right: can smart thermal storage work for both customers and grids?* Consumer Impact study, RealValue project Horizon 2020. Environmental Change Institute, University of Oxford https://www.researchgate.net/publication/327071033_Getting_the_balance_right_can_smart_thermal_storage_work_for_both_customers_and_grids_Consumer_impact_study_RealValue_project_Horizon_2020_Environmental_Change_Institute_University_of_Oxford_Darby_SJ_DNV KEMA (2013) *Energy & Sustainability. Potential for smart electric thermal storage. Contributing to a low carbon electricity system*. Report for Glen Dimplex and SSE plc by Raadschelders, J., Sikkema, F. and in t'Groen, B.

Eyre, N., Darby, S.J., Grünewald, P., McKenna, E. and Ford, R., (2018) Reaching a 1.5C target: Socio-technical challenges for a rapid transition to low carbon electricity systems. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*

Faruqui, A. and Sergici, S. (2013) *Arcturus:* international evidence on dynamic pricing. *The Electricity Journal* 26 (7), 55-65

Fell, M., Shipworth, D., Huebner, G.M. and Elwell, C. A. (2015) Public acceptability of domestic demand-side response in Great Britain: the role of automation and direct load control. *Energy Research & Social Science* 9, 72-84

Flett, G., Kelly, N. and McGhee, R. (2018) Review of UK Energy System Demonstrators. UK Energy Research Centre, London. http://www.ukerc.ac.uk/publications/review-of-uk-energy-system-demonstrators.html

Gram-Hanssen K. (2010) Residential heat comfort practices: understanding users. *Building Research & Information* 38 (2), 175-186

Grünewald, P. and Torriti, J. (2013) Demand response from the non-domestic sector: early UK experiences and future opportunities. *Energy Policy* 61, 423-429

Grünewald, P. and Diakonova, M. (2018) Flexibility, dynamism and diversity in energy supply and demand: A critical review. *Energy Research & Social Science* 38, 58-66

Köhrsen, J. (2018) Exogenous shocks, social skill, and power: Urban energy transitions as social fields. . *Energy Policy* 117, 307-315

Leach, G. (1992) The energy transition. Energy Policy 20 (2), pp116-123

McKenna, E., Higginson, S., Grunewald, P. and Darby, S.J. (2018) Simulating residential demand response: Improving socio-technical assumptions in activity-based models of energy demand. *Energy Efficiency* 11, 1583-1597

Moss, T., Becker, S. and Naumann, M. (2015) Whose energy transition is it anyway? Organisation and ownership of the *Energiewende* in villages, cities and regions. *Local Environment* 20:12, 1547-1563

O'Connell N., Pinson P., Madsen H. and O'Malley M. (2014) Benefits and challenges of electrical demand response: a critical review. *Renewable and Sustainable Energy Reviews* 39, 686-699

Ornetzeder, M. and Rohracher, H. (2006) User-led innovations and participation processes: *lessons from sustainable energy technologies. Energy Policy 34 (2), 138-150*

Pachauri, S. and Jiang, L. (2008) The household energy transition in India and China. *Energy Policy* 36 (11), 4022-4035

Pawson R. and Tilley N. (1997) An introduction to scientific realist evaluation. In *Evaluation for the 21st Century: A Handbook*, eds. Chelimsky, E. and Shadish, W.R. Sage, ISBN 0-7619-0611-8

Pallesen, T. and Jenle, R.P. (2018) Organizing consumers for a decarbonized electricity system: Calculative agencies and user scripts in a Danish demonstration project. *Energy Research & Social Science* 38, 102-109

Parag, Y. and Janda, K (2014) More than filler: middle actors and socio-technical change in the energy system from the 'middle out'. *Energy Research & Social Science* 3, 102-112

Sauter, R. and Watson, J. (2007) Strategies for the deployment of micro-generation: implications for social acceptance. *Energy Policy* 35 (5), 2770-2779

Schuller, A., Flath, C. and Gottwalt, S. (2015) Quantifying load flexibility of electric vehicles for renewable energy integration. *Applied Energy* 151, 335-344

SEDC (2015) *Mapping demand response in Europe today*. Smart Energy Demand Coalition

Steemers, K. and Manchanda, S. (2010) Energy efficient design and occupant well-being: case studies in the UK and India. *Building and Environment* 45 (2), 270-278

Torriti, J., Hassan, M. and Leach, M. (2010) Demand response experience in Europe: policies, programmes and implementation. *Energy* 35 (4), 1575-1583

Torriti, J., Hanna, R., Anderson, B., Yeboah, G. and Druckman, A. (2015) Peak residential electricity demand and social practices: Deriving flexibility and greenhouse gas intensities from time use and locational data. *Indoor and Built Environment* 24 (7), 891-912

VaasaETT (2012) EMPOWER DEMAND 2: Energy Efficiency through Information and Communication Technology – Best Practice Examples and Guidance. VaasaETT Global Energy Think Tank, Finland. https://esmig.eu/resource/empower-demand-report-phase-ii

VaasaETT (2019) The Role of Data for Consumer Centric Energy Markets and Solutions. https://esmig.eu/resource/report-role-data-consumer-centric-energy

Wolsink, M. (2012) The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources. *Renewable and Sustainable Energy Reviews* 16 (1), 822-835

Acknowledgements

My thanks to colleagues on the *RealValue* project, which supplied the case studies for this paper, especially Sarah Higginson, Marina Topouzi, Julie Goodhew and Stefanie Reiss. The project was funded by the European Commission through the H2020 programme; this funding, and the European collaboration it fosters, are gratefully acknowledged.

The University of Oxford Martin Programme on Integrating Renewable Energy and the UK Energy Research Centre have supported my work on demand response and funded the writing of this paper. A draft version of the paper was presented at the seventh International Academic Symposium hosted by the Chair of Energy Sustainability at the

University of Barcelona, on the theme ‘Smart Energy Systems from a New Energy Policy Approach’.