Demand response beyond the numbers: A critical reappraisal of flexibility in two United Kingdom field trials

Abstract
Domestic demand response – specifically, changing household electricity usage patterns in response to signals – is an increasingly important part of electricity system decarbonisation. Many forms of demand response exist and there is a live question of the most appropriate and fair way to design it, especially regarding which types of household can participate and how.

Using secondary qualitative analysis of published trial documentation, this paper compares two UK based trials in low income households whose headline results – kW peak reduction - differed by two orders of magnitude. Using a framework based on flexibility capital, the contextual factors underlying these different peak reductions are examined, and these headline results are balanced against other outcomes of the trials. The analysis examines the technical and social sources of flexibility capital in each trial, who controlled this capital, and for whom it delivered value. This highlights questions to consider when designing demand response, such as to what extent participants should be expected to understand and actively participate, who should control their energy use and the spread of responsibility and liability across facilitating parties.

We argue that critical reappraisals of existing evidence are necessary as the terms for consumer participation in the future energy system are being established. There exist important aspects and consequences of demand response that are overlooked if schemes focus solely on how many Watts can be shifted. This is crucial as governments, the private sector and a growing number of other parties test and implement different demand response strategies.

Key words
Demand Response, Direct load control, Critical Peak Rebate, Flexibility capital

1. Introduction

As countries seek to decarbonise their energy systems, it is anticipated that substantial proportions of heating, cooling and transport energy demands will be met by renewable electricity sources. This in turn will require more demand response (DR), or “changes in electric usage by end-use customers from their normal consumption patterns” [1], in order to make best use of varying amounts of wind and solar generation and manage network constraints at different scales. However, uncertainty exists concerning the societal impacts that a more flexible and time sensitive energy market will bring. Governments around the world are interested in understanding which consumers will benefit from DR and in what ways; from lower cost energy to improved comfort and housing conditions. Energy social scientists have a role to play in producing evidence for industry and policy makers through DR trials. Furthermore, in line with current calls for responsible innovation [2] and mission-oriented innovation [3] we also have a role to continually reflect critically on this evidence, to contextualise it and reappraise it in reference to current and future societal and environmental impacts.

Empirical work is useful to understand the real world impacts of different DR design choices, and previous studies have begun to explore the social impacts of DR through examining the interaction between flexibility, social norms and social practices [4,5]. To contribute to this debate, this paper contrasts two field trials of domestic DR in the UK. Both were run in low-income housing, but used different technologies and took opposite approaches to consumer participation. The first used direct load control of heating systems to deliver large peak-time electricity demand reductions with minimal participation of the tenants. The second successfully incentivised consumer participation, but delivered minimal peak reduction. The two projects fall at different positions within the flexibility capital matrix develop by Powells and Fell [6], who define flexibility capital as “the capacity to responsively change patterns of interaction with a system to support the operation of that system”. Participants in the first, a heat pump trial, could be broadly viewed as having high flexibility capital largely derived through technological means. Participants in the second trial, who did not have large automated loads, had relatively low, predominantly socially derived, flexibility capital. This paper uses published evidence from these trials to reflect on how flexibility capital was created, by whom it was controlled, and for whom it delivered value.

In Section 2 we present relevant literature on the evolving DR market; in Section 3 the analysis method is described and the two cases are detailed in Section 4. Section 5 presents the cross case comparison structured around key concepts in flexibility capital. The Discussion in Section 6 reflects on implications for future DR design and the Conclusion summarises some key messages and describes the relevance for different readers.

2. Background

2.1 Demand Response: delivery mechanisms and response sizes

The drive to unlock demand-side flexibility is nothing new. Methods of influencing patterns of electricity demand to optimise use of the grid have been sought and employed for well over a hundred years [4], and include for example the Economy 7 tariff in the UK and Tempo in France [5]. However, this long experience is of limited value when the kinds of change in electricity usage patterns required now are different (e.g. following variable renewable generation), as are the technologies employed to help enable them (such as heat pumps and home batteries with smart controls). Substantial research effort is therefore still directed at understanding how best to unlock system flexibility, utilising new market mechanisms whilst matching consumer need.

The amount of DR available depends on the size of load available (i.e. how much electrical power a device consumes) and the extent that it can be influenced. In the domestic context, this combination might involve factors such as the presence or absence of a heat pump or electric vehicle (EV), the readiness and ability of the householders to participate in a demand response programme, and how household routines affect both consumption patterns and their susceptibility to influence. These in turn may depend on characteristics of both the home and household members [4,7,8]. All of these factors contribute to the amount of flexibility capital a household is viewed as possessing.

DR can be delivered by operators in a variety of ways. The main distinction is between direct and indirect methods. *Direct methods* involve an operator directly adjusting the electrical consumption of end-use technologies, such as turning appliances off and on or heating/cooling settings up and down. This is often called 'direct load control'. This method has the benefit of allowing quick, reliable, and potentially large changes in electricity usage, so long as these actions are not overridden by users. This requires appliances to have the technical capacity and connectivity to be externally operated and for users to sign up to this arrangement. *Indirect methods,* on the other hand, aim to motivate end users to adjust their electricity consumption using price or other signals without any direct connection between the operator and the end use appliance [9]. Here, the magnitude of response is determined by users reacting to such signals, either manually or through the utilisation of technologies that automate their response based on their personal preferences. A time-of-use tariff, where the unit cost of electricity for the end user shifts to incentivise higher use at lower cost times, is an example of an indirect method.

There is consistent evidence that direct load control and indirect methods which use automation technologies lead to significantly larger responses than a reliance on manual response to signals [10,11]. For example, a review of different DR pilots found critical peak rebate schemes (a form of time-of-use pricing) delivered an average 12% reduction during peak 'critical' periods which rose to 20% when consumers had technologies to automate responses [12]. The review also pointed to a unique pilot that achieved an average 41% reduction in critical periods when the utility directly controlled consumers' appliances.

2.2 Demand response: impacts on different groups

Where does this leave the householder? By enrolling people in DR programmes, operators are effectively using technologies in their homes - likely to be intimately linked with their daily lives - as means to achieving some desirable end, such as selling more or less electricity at certain times, or avoiding the need for network reinforcement. Typically, some monetary or other incentive is offered to promote flexibility provision, or by way of recognition for participation. While the goal of this enterprise may often be societally important (i.e. having a clean, functional and affordable energy supply), there is concern that some households may either be unreasonably burdened by the expectation to provide flexibility, or may miss out on the ability to benefit by providing it [6].

The state of the evidence regarding these concerns can best be characterised as limited and mixed, but growing [13]. In relation to direct economic outcomes for participants, two large UK trials including varieties of time of use pricing, Customer Led Network Revolution [14] and Low Carbon London [15] found no significant differences in economic impacts between consumer classification groups, although the latter trial deliberatly avoided recruiting those deemed vulnerable [16]. A review of DR pilots in Europe by VaasaETT discovered no consistent economic impacts associated with demographic factors [12]. In the US, a field trial aiming to explore relative impacts of a critical peak pricing scheme on vulnerable (i.e. elderly, chronically ill or low income) customers found that they generally fared no better or worse than their non-vulnerable counterparts. However, in a large US time-of-use field trial elderly and disabled participants experienced greater negative economic impacts under some circumstances, while disabled participants also experienced negative health outcomes [17].

Turning from trials to commercial offerings, Sherwin et al. [18] found that uptake of a direct load control programme for air conditioners in California was lower amongst low income groups, although (as a descriptive study) the reason for this is unclear. Research on other aspects of the energy system points towards more energy-vulnerable households being less likely to engage in change, for example evidence from the UK suggests that factors including being on a low income, being a renter, and having lower qualifications are associated with a lower tendency to engage with the energy market by switching tariff [19]. It is important to note, in the UK, contrary to the situation discovered by Sherwin, the bulk of current domestic demand response is achieved through the Economy 7 tariff, disproportionately present in households that are on average older, less affluent and less well educated than the general population [20]. This prevalence, in part, is because electric heating has tended to be installed in high-rise social housing blocks that are unable to have gas heating installed, or households are unable to afford a new wet system installation that is required to move to gas central heating.

Other recent scholarship has taken a broader justice perspective on energy transitions in which the provision of flexibility plays a prominent role. Milchram et al. [21] draw on a comparison of four smart grid case studies in the Netherlands, and highlight how wider aspects of scheme design (such as level of automation) impact on inclusion and user agency, with implications for recognition and procedural justice. Similarly, findings from deliberative workshops run by Thomas et al. [22] highlight a key concern of participants that "differences in needs and abilities ought not […] to affect the status of vulnerable groups as equal participants in more flexible energy systems" (p8).

This emerging picture suggests that increased attention to impacts of DR on different groups is necessary, and that it is important to go beyond headline metrics such as peak load reduction or energy bill savings, which risk missing other potentially similarly significant impacts in other aspects of life. This paper will contribute to the literature on low income household participation in DR by exploring the contextual factors which enable or prevent participation and reflecting on who realises the benefits.

3. Method

The method applied in this paper is a cross-case comparison of two domestic DR trials, using Secondary Qualitative Analysis, and interpreted through a flexibility capital framework. The two trials to be compared are referred to as NEDO and Energywise. These two cases were selected as they were both undertaken in social housing with the support of housing providers, but used contrasting DR types. In one, automated heat pumps were installed and operated by a third party to generate large reductions in peak load with little engagement from the residents. In the other, residents were incentivised to flex their own, much smaller, loads.

The qualitative comparison uses flexibility capital as a framework to compare these two very different approaches to delivering DR, focussing specifically on differences in the two key attributes Powells and Fell raise [23]: the *source* of the flexibility capital (from technical to social) and the *controller* of the capital (from self to other). Our interest is in understanding how the two trials developed the flexibility capital of participating households, how this capital delivered economic or other value to the different parties involved, and finally the fairness of the different approaches.

The method draws on Secondary Qualitative Analysis to review published trial data. Specifically we use it to 'combine data from two or more primary studies for purposes of comparison' for 'amplified analysis' [24]. Driven by the increasing commitment to archive and share qualitative data, Secondary Qualitative Analysis has emerged as way to reinterpret public data sets. Here we use it to compare evidence from two trials which used multi-disciplinary research methods, generating qualitative and quantitative data. The trials were not designed to explore questions of flexibility capital, but the data they generated contains relevant evidence.

Secondary Qualitative Analysis is commonly used by researchers to re-examine data sets they have been involved in creating. The authors of this paper were involved in the two trials as academic partners or evaluation researchers and our collaboration to produce this paper is driven by the call for energy social science to produce more rigorous, societally useful and policy applicable research [25].

4. Description of cases

4.1 Energywise

The first DR case, Energywise, was a field trial of smart meters, a time of use (ToU) tariff and a critical peak rebate (CPR) which ran between 2014 and 2018. It was funded through the Low Carbon Network Fund, a UK government regulated fund that enables distribution network operators (DNOs) to test new technologies and approaches. The Energywise project consortium was led by UK Power Networks DNO and included British Gas (one of the UK's largest energy companies), two social housing providers providing housing in one of London's poorer boroughs (Tower Hamlets), as well as academic partners UCL, consultancies CAG Consultants and Element Energy, NGO National Energy Action, and community organisation the Bromley-by-Bow Centre.

The project's overarching aim was to explore the means to encourage increased participation of fuel poor customers in energy efficiency and in variable tariffs [26]. Within this, the DNO aimed to investigate network impacts of DR as well as explore ways to partner with community-based organisations and support fuel poor households to engage with DR markets [27]. For the energy supplier the trial was an opportunity to install smart meters in existing customers' homes and develop new metering technologies such as their first SMETS1 compliant prepayment meter [27]. The housing providers supported recruitment. The project plan was subject to ethical review by UCL Ethics Board and had a number of participant support and safety mechanisms, including remote temperature monitoring to identify households under heating their homes in response to the trial [28].

The project was composed of two trials. Trial 1 was a randomised control trial of smart metering and interventions aimed at reducing domestic electricity consumption. Trial 2 focussed on electricity use shifting and was an experimental trial of two DR products, a ToU tariff offered to households with credit meters and a critical peak rebate (CPR) offered to households with prepayment meters. The CPR product is the focus of this paper[1].

The CPR scheme was a non-punitive financial mechanism offering participants a rebate on their electricity payments if they reduced their household's electricity consumption during designated peak events called 'bonus times' and had no consequences if they did not. The bonus times were 3-6 hour periods typically on weekday evenings. Participants consented to receive a text message on their phones notifying them of a peak event. Each month they were sent a payment direct to their smart meter crediting them with 10 times the amount of electricity they had managed to save during the month's events. This was made possible via a prepayment smart meter developed by the energy company.

Demand response per customer per peak event was calculated from the reduction in half hourly electricity use compared to a constructed baseline for each customer. This is an indirect calculation method as there was no way to monitor or measure exactly what each household did or whether the observed reduction was intentional, coincidental or a result of the way the baseline was constructed.

The target population was vulnerable customers: social housing tenants in a borough with a high proportion of Bengali-speaking households and scoring highly on indices of multiple deprivation. An intensive engagement process was used to recruit prepayment households already in Trial 1 which led to a 75% uptake. The project was therefore viewed as a positive example of supporting social housing tenants to participate in DR activities [27].

The quantitative results of the trial are presented in detail in the published project documentation [27]. Despite the high level of enrolment, the results for the energy system were very small: the aggregated peak demand was reduced by 1.5%, translating to around 7W per household. Furthermore, qualitative research revealed the relationship between domestic labour and demand shifting, which was often carried out by women [27,29]. This raised questions about increasing the burden of unpaid domestic labour. It also showed some issues, for example

[1] Full details of the trial design and methodology are available on UK Power Networks' website http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Energywise/.

the consentee not explaining to the person in charge of the household chores that they were in a CPR trial, and the difficulty in linking demand shifting to financial rewards (see pp 48-51 in [27]). The CPR trial therefore provided very useful insight on questions of uptake and equity of DR, but did not deliver a meaningful demand response in terms of kW peak reduction.

4.2 NEDO Greater Manchester Smart Communities

The second DR case study was an initiative of the Japanese government's ministry for energy: the New Energy and Industrial Technology Development Organisation (NEDO)[30]. This took place between 2014 and 2017. NEDO partnered with the UK's government department of Business, Energy and Industrial Strategy (BEIS), The Greater Manchester Combined Authority, and three Manchester Arms Length Management Organisations (ALMOs) who provide social housing. The Japanese government involvement was through a grant to support Japanese businesses break into new markets overseas. These businesses, who also contributed funding, were focussed on aggregation of DR obtained through direct load control of a large number of domestic heat pumps. The business objectives for the Japanese government and private sector were to develop and trial DR enabled heat pumps, test DR aggregation technologies, and to establish sustainable business models for electricity aggregation within the UK market [23]. The ALMOs benefited from involvement through receiving free heat pump systems, with the additional benefit of receiving the Renewable Heating Incentive subsidy for heat generated using these systems, and an expected reduction of the energy costs for their participating households.

The three social housing providers together brought 550 households into the project, each household having their old (electric storage or gas) heating system replaced with an air source heat pump and broadband connection. Heat pump manufacturers intended for heat pumps to be left on all the time, so that the manufacturers were then able to act as the load controller and switch the heat pumps off to deliver flexibility. A number of different types of flexibility were trialled; here we focus on heat pumps being switched off at times of peak demand. Such DR events were carried out for 60-120 minutes during morning and evening peaks, relying on the thermal inertia of the building fabric to retain heat and maintain comfortable conditions for the occupants. Households were automatically opted in to every DR event unless the internal temperature was below 18°C or dropped below 2°C of the set temperature, if the household adjusted the temperature control, or if they pre-opted out [23]. Thus, the installed technology was critical to the trial: unlike the Energywise trial, the premise of the NEDO project was that given the right technology, DR could occur independently of occupant involvement.

From a technical perspective the project achieved substantial DR. The consortium's target of 200 kW was achieved in 28% of the test half hours, with a maximum DR of 375 kW [23]. Peak reduction per household is not reported (either individually or on average across all households), as the aggregated total kW was the metric of interest to most of the stakeholders. In order to compare the results to the Energywise trial, here we divide by the total 550 households to obtain a result of 360 W per household being achieved in 28% of the test half hours, and a maximum of 680 W per household.

From the householder perspective, social research undertaken by the project board found a very low understanding from households of what a DR event was [30]. Aside from not being sufficiently explained at the start, this limited awareness could have been reinforced by several factors. The heat pump and control system for carrying out DR were installed and set in use at the same time, so the householders did not realise the existence of two separate aspects. Households also did not directly earn money from the DR events, meaning contact about the DR pilot post installation was limited. Households were given the opportunity to engage with the DR using computer tablets provided, which had the functionality to pre-opt-out of a DR event. However, 70 telephone interviews undertaken found only rare use of this functionality, likely due to lack of awareness of the DR itself [30].

Despite most participants not realising that DR was taking place before the trial or notice it during the trial, the majority interviewed did not mind that their heat pumps were being externally controlled when it was explained during an interview. This was not the case for all households, some reporting being less supportive of this control over their heating being granted to the external party [30]. The majority of interviewed participants were satisfied or extremely satisfied with their heat pump, with most reporting saving a modest amount of money on energy bills and experiencing higher comfort with the new system. More vulnerable households who were at home all the time liked the greater consistency of temperature than they had with storage or gas; hence, there was a strong prioritisation of comfort over cost or control.

5. Cross-case comparison

In this section we apply secondary qualitative analysis using a flexibility capital framework to reframe and compare the data published in the trials' reports. These reports contain detail on the technologies installed, how they were operated, the role anticipated for occupants to play in demand shifting, the protections used, the experiences of households during the trials and the management of any technical faults. We compared these details to identify the source and the control of the flexibility capital generated in the trials.

5.1 Comparison of quantitative results

The two trials are first compared by their key technical outcome of kW peak reduction per household. The NEDO trial reliably achieved 360 W per household, while Energywise achieved an average of 7 W per household. Thus, the NEDO trial achieved orders of magnitude greater peak reduction than the Energywise initiative. However, both trials achieved their target or expected peak load reduction, derived based on previous empirical trials. These were 1.6% of the peak (around 8 W per household) in Energywise [27] and 200 kW over 550 households (360 W per household) in NEDO [30].

5.2 Flexibility capital framework

To explore the difference in quantitative savings outlined above through the lens of flexibility capital, firstly the application of Powells and Fell's flexibility capital framework to contextual factors in the case study field trials is summarised in Figure 1. This positions the case studies on two spectra: *technology vs socially derived*, and *self vs other*. While flexibility capital is socio-technically derived, units such as households may differ in the relative contribution that social or technical factors may make. Those whose flexibility capital is more *technology-derived* will tend to have access to larger loads available to shift, and/or storage, and/or greater dependence on automation. *Socially-derived* flexibility capital instead originates from changes in household routines and practices in order to shift or reduce energy consumption. *Self vs other* refers both to who operationalises the flexibility (the 'end-users' or external agents), and on whose terms the choice to economise flexibility capital is made.

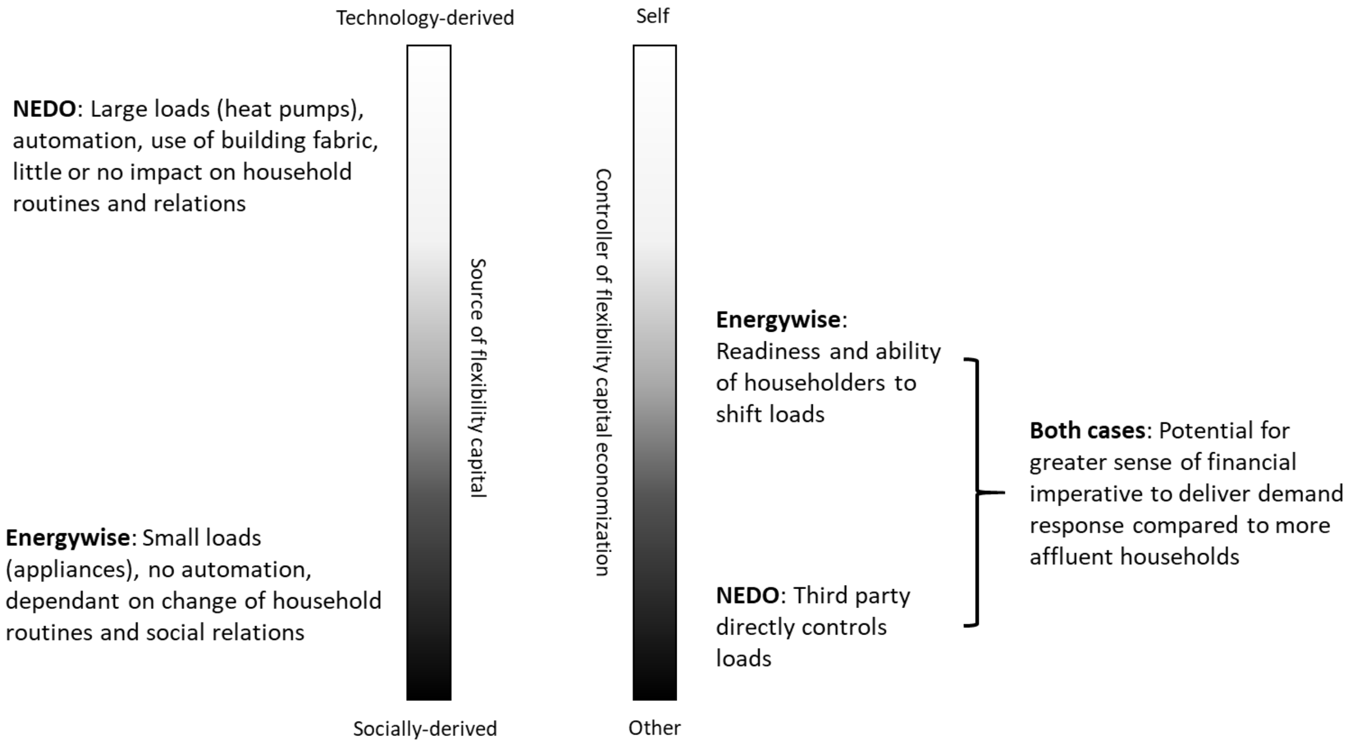

Figure 1. Two key spectra in Powells and Fell's flexibility capital framework with position of case study trials shown.

5.3 Sources of flexibility capital

To understand the sources of flexibility capital being operationalised, we compared the descriptions from the trial reports on the intended role for the households and the technologies involved to deliver demand shifting.

From a technology perspective, the first major difference between the trials was the size of the load available for shifting. For the Energywise households, who were all living in social housing with gas central heating, the largest loads typically available were washing machines and electric heaters. Typical power and energy consumption for a washing machine is up to 3 kW, or 1-2 kWh per use, and for an electric heater is 2.5 kW, or 2.5 kWh if used for one hour [31]. The NEDO trial households also lived in social housing, however opting into the trial meant participating households had their heating systems replaced with heat pumps. The electrical capacity of a heat pump in the NEDO trial was 4-8 kW, which if maintained for 60-120 minutes could use (or save, if curtailed) 4-16 kWh.

The NEDO trial also benefited from increased technology derived flexibility capital in the form of energy storage. The use of energy storage enables delivery of energy services to continue during DR events. In the NEDO trial, the thermal inertia of participants' homes was relied upon to maintain comfortable thermal conditions while heat pumps were switched off during DR events. The Energywise trial did not exploit energy storage; instead, participants were incentivised to use electrical energy services outside of DR event time. It is noteworthy that it had been the intention to install dedicated heat storage in the NEDO trial in the form of buffer vessels to increase the amount of time the heat pumps could be turned off - yet in the end few of the selected properties had enough space to install these [30], therefore providing a limit to technology-derived flexibility capital. This is significant because other DR trials relying on building fabric storage only have shown some issues with overheating [32,33], highlighting more complex potential links between affluence, space availability and flexibility capital.

The two trials differed substantially in their approaches to socially derived flexibility capital. Energywise focused on building households' capacity to flex their consumption through training, education and ultimately manual consumption shifting. Conversely, NEDO focused on system automation, where household involvement in the alteration of settings was suboptimal. This is expanded upon below.

Energywise participants had to develop their own response strategies to the DR prompts. The team provided guidance about different appliances' typical consumption, but participants themselves had to negotiate their own household routines, and gauge which of their loads could be flexed by whom during a DR event. This allowed some households to respond creatively, increasing their understanding of their electricity consumption. This therefore provided them the opportunity to manage their electricity consumption to support other household priorities (e.g. environmentalism, financial discipline, social benefits). However these strategies were also constrained by the electric appliances households had, as well as by who typically used the appliances. Some participants managed to align their own and their household's use of appliances with the DR schedule; other participants did not.

Energywise succeeded in achieving a high level of recruitment to this particular trial (75% of those who already participated in a previous trial phase). However, the number of households actively participating in each DR event was unknown, and qualitative research suggests it was lower than the trial recruitment rate would imply [27]. Of 11 households interviewed, one was actively shifting their consumption and two others were trying. They discussed delaying laundry during a DR event, and changing their oven use. They also discussed the difficulties of shifting stemming from the requirement to manage family life, or because of already trying to spend little on electricity. The other seven households had opted in to the trial, but were not able to actively shift during DR events. Reasons included misunderstanding the offer, and the householder who signed up to the offer not being the same person as the chore-doer.

This dependence on householder engagement and participants' creative management to achieve flexibility strongly contrasts with the NEDO trial, where all households participated in DR events by default and most participants did not realise they were providing DR. This resulted in an average opt-out of 10% of customers [30], implying an average 90% participation rate per event. Of those who opted out, around half was due to the automatic safety-stops implemented by the system and half was due to tenant-initiated opt-out.

5.3 Controllers of flexibility capital

To understand the control of the flexibility capital we compared the actual mechanisms used to deliver demand flexibility in terms of the management of the technical systems installed and the participants' accounts of what they themselves did. We compared the protections in place during the trials, any technical glitches and how they were solved as well as the economic incentive structure and benefits identified by the parties. This helped identify where control of the flexibility capital lay.

There were important differences, but also some similarity, between the two cases in terms of where control over flexibility capital could be seen to reside. In the NEDO trial, DR was instigated directly by an external party through control of heating systems. In Energywise, on the other hand, it was up to participants themselves to decide whether or not to respond to DR signals. In this respect economisation of flexibility capital was more other-controlled in NEDO, and more self-controlled in Energywise.

The external control of heating systems in the NEDO trial was not purely optimised to provide grid benefits but also to protect participants. DR events were governed by control logic which stopped them occurring under certain conditions (see Section 4), in order to maintain a certain minimum temperature for the participants. However, viewed through a flexibility capital lens, NEDO households were therefore unable to decide when was best for them to provide flexibility services, with only those who were more IT literate able to override DR events through use of the online app.

Automating the DR had wider consequences in that NEDO participants were not expected to engage with their heating system at all; project documentation states that 'do not unplug' labels were placed on installed cables, with letters sent to all tenants requesting they do not touch any equipment. Thus, whilst social research has demonstrated how heating practices form part of social life, the NEDO trial was designed to circumvent this domain of social practice. However, in addition to an average of 13 visits to each property for technology installation and commissioning, there were 482 call outs across the 550 properties in one year showing that the aspiration of leaving the equipment to work without the participants was not achieved. The project report states that "many call outs were due to "tenants' lack of knowledge of their new heating system and included calls relating to radiators not being as hot as their previous system, tenants inadvertently switching their HP system off and reports of heating systems being turned off during a DR event" [see pg.22 30]

In contrast, Energywise participants were in control of their own DR behaviour. This control was dispersed across household members who all used electricity, but had different perspectives on what could be flexed and what value this flexibility would deliver for the household. Sometimes the control of this capital was negotiated explicitly, for example a family discussing how their household routine could be fitted around a CPR event. Sometimes the negotiation was implicit, such as the electricity-bill-payers who did not tell their chore-doing partners that their household was on a CPR trial to avoid affecting the domestic management [34]. Energywise participants were also aware that their ability to control their flexibility was limited by other areas of household life. Broken down appliances, low levels of electricity consumption and conflicting family schedules were identified as limiting factors by those households that were explicitly seeking to generate value by controlling their flexibility [35].

While recognising these differences in how flexibility capital was controlled in each case, there is also an important similarity between them (see Figure 1), "Both cases" note to right-hand side). Both trials were enabled through the participation of landlords, and offered the prospect of some financial benefit: either direct rewards in the case of Energywise, or a new heating system with improved comfort/cost efficiency in the case of NEDO. This context has implications when compared with how similar flexibility products might be experienced in the population more generally. The main one is that the imperative to realise benefits such as these may be perceived more keenly in our cases than amongst households which are more affluent and/or already have good heating systems. A small financial reward is likely to make a more meaningful difference to the daily finances of a less affluent household than a more affluent one. Similarly, the disruption involved in getting a new heating system and making it available to external control may feel more like a necessity for those whose heating systems currently functions poorly. The ultimate implication of this is that the decision to offer up demand side flexibility may feel less fully voluntary for some households than for others – although this is a question which further research could usefully investigate.

5.4 Value derived from flexibility

This section explores in more detail how controlling the flexibility capital delivered economic or other value to the different parties involved, considering the benefits and costs.

In both trials, the social housing providers were keen for the pilots to lead to lower energy costs for participants. However, as mentioned in Section 2, involvement in DR projects does not necessarily lead to financial savings. Whilst in Energywise the DR offering was designed to be non-financially punitive, in NEDO a minority of households reported increased energy costs. It is not possible to attribute the increase to the DR specifically as opposed to the change in heating system; previous work has found increased energy costs arising from installation of heat pumps [36,37]. Comfort was also increased although this was not measured in the trial.

The technologies used in the two trials had very different capital costs, met through different models of financing. The NEDO trial used technologies that were more expensive; heat pumps and the associated communication and aggregation infrastructure. There were additional financial costs to the distribution network operator, who undertook minor network reinforcements, and for the ALMOs and local government association including for project management, recruitment and installation including replacement of radiators and pipes, and broadband installation for the DR trial duration [see pg.12 30]. Costs incurred by the ALMOs were indirectly subsidised through a government grant for eligible heat pumps. Households did not have to contribute financially to the new heating system installation nor the DR technologies.

In comparison, Energywise did not require economic capital; instead only a standard electricity smart meter and in-home display were required to participate. These technologies were installed by the energy company and paid for directly through UK energy bills. Significant costs were instead incurred by customer outreach and information resources including bilingual face-to-face support. Again, households faced no economic cost for participation.

Ultimately, care must be taken when commenting on financial costs and benefits since neither trial was situated within a real energy market: Energywise included bill protection for participants and the market value for the aggregated peak reduction in the NEDO trial is currently theoretical. However, in a future where this aggregation method has market value, the aggregator will earn revenue by providing this flexibility. It is also expected that there would be some form of financial benefit for individual households as well as housing associations who allow or even promote households under their management to engage in energy aggregation schemes.

Non-economic sources of value were intended and achieved in the Energywise trial, because the aim was to increase participation of fuel poor customers in energy markets. In order for high levels of participation to be realised, consumer information was key and outreach was prioritised by the project. This engagement was valued highly by the participants: in the final trial survey around 95% of 105 respondents (both CPR and ToU participants) felt their household had benefitted in at least one way from the trial and the majority were ‘now more aware of how to save energy’ [27]. The increase in energy literacy and high level of participation should be interpreted in reference to the significant resources required to deliver participant information and outreach. Without this support it is debatable whether low income households would acquire this knowledge and may find their energy costs rising if they do not identify the best tariff for their household.

5.6 Summary of cross-case comparison

In the NEDO study, participants could be viewed as having high flexibility capital due to the presence of heat pumps with a relatively high and flexible electricity demand. This capital was largely derived through technological means, with direct control of heat pump activity having little apparent impact on the majority of participants’ own activities or comfort. However, the main controller of their flexibility capital (i.e. the actor with most influence over how it should be deployed) was not the participants but the programme operators. While participants felt little discernible impact, they also had little meaningful say over how their flexibility capital was applied, and received no reward in the form of incentives for DR events that took place within their property.

The Energywise participants, conversely, had relatively low flexibility capital due to the general absence of high-powered, flexible appliances. Where Energywise participants were able to be flexible, this appears generally to be due to active changes in the use of appliances and, likely, the performance of practices in which these appliances played a role. Thus, their flexibility capital was predominantly socially derived. While it was completely up to participants whether or not to respond to DR events, some households may have felt financial pressure to do so, and the resulting shifting activities may have been viewed as coming at some cost to comfort or convenience – or may have been difficult or impossible for other reasons such as lack of awareness by chore-doers of events. The next section discusses the implications of these interpretations for DR design.

6 Discussion: Implications for DR design

The two trials described in this paper demonstrate the potential for the DR market to deliver a range of benefits for the energy system and for energy consumers; however this is highly dependent upon the technical and social contexts, and has the additional potential to create injustices. This is an evolving field in which questions on fair and appropriate ways to carry out DR for domestic energy consumers continue to be explored. Understanding who gains from the development of flexibility capital, and its utilisation, is integral to understanding how it will be perceived by the public – with perceived 'unfair' outcomes having potential to reduce public acceptance of new technology innovations [38]. In this section we discuss key contextual aspects of DR, articulating some general questions academics, industry, policy makers and housing providers should ask when considering and undertaking DR design.

6.1 DR design: Socially vs. technology-derived

The case of Energywise illustrated socially derived DR which required the orchestration of household routines and changing appliance use. This may lead to an increase in household management as chore-doing is flexed according to DR signals. The NEDO trial illustrated technically derived DR which prioritised direct load control over meaningful participation by household members. This led in some instances to suboptimal use of the technology by households where the automation that delivered the flexibility was overridden.

This raises the dilemma: Should DR design attempt to limit any impact on domestic management, by focusing on appliances which can be controlled remotely by residents or flexibility service providers? Doing so could reduce household burden but also constrain the forms of participation available. Without being able to afford investment in these loads or smart home systems, some low-income and low electricity consuming households would be excluded from the DR market and lose the associated benefits that Energywise participants identified such as better understanding of energy use in the home and a sense of contributing to a better energy system.

6.2 DR design: Self vs. other

Flexibility can be operationalised by the 'end-users' or by external agents, and Powells and Fell draw attention to this with their 'self-other' spectrum. The two cases in this paper fall on different places on this spectrum and elicit some issues to reflect on when considering DR design with respect to it.

The first issue is that DR design can either facilitate or inhibit human agency - the capacity of the 'self' to act. The trials mirror two opposing visions for the role of the user in DR highlighted by Goulden et al. [39]; one vision relies on DR optimisation based on automation where households are not expected to have to micro manage energy decisions, the other encourages or relies on active participation. The NEDO trial minimised the need for participants to be actively engaged in energy management, therefore reducing the need to explain what the technology was and what it was doing. The focus was on enabling the technology to produce a response, and to limit any acts of 'resistance' from participants. In contrast, Energywise aimed to improve participants' understanding of the energy consuming appliances in their homes and how their use of these could generate value for the energy system and for themselves. The project prioritised active engagement and achieved high trial opt in and project satisfaction rates [27]. However, this also meant allowing people to not act on calls for a response if they did not consider the savings or interruption worthwhile. Therefore, high and active opt in to a tariff or trial does not necessarily lead to high DR event participation or large shifting. Similarly, if people are enrolled into a DR trial without a full understanding of the system complexity, will they consume electricity in ways which are not in line with the operators' priorities and will this expose them to negative outcomes such a drop in comfort or an economic penalty? In addition, do we risk resistance, and households withdrawing participation if they feel they do not have control over their energy services?

The second issue is the distribution of responsibilities along the spectrum of self vs other. The trials illustrate that responding to DR requires skills, knowledge and action and that these can be located differently amongst the contributing parties; DR design therefore needs to take into account how the burden of responsibility is distributed and ensure the parties are properly resourced to manage this. The Energywise trial aimed to build the knowledge and skills needed to respond to DR calls within households directly, providing outreach and information resources to achieve this, whilst the technical and financial liabilities for the DR offer remained with the energy company. The energy company piloted new smart prepayment metering technology, they commissioned bespoke communications technology to include households living in multi-unit dwellings, and they also had to take on the cost of reimbursing participants when there was a loss of function for some smart meters obscuring a household's DR response [40]. These innovation activities fall within their usual domain of responsibility.

By contrast, the NEDO trial created new areas of responsibility for the parties involved. The 'newness' of the technology meant that there were a number of hurdles to overcome to get the technologies installed and keep them operational. The Combined Authority coordinated the three housing providers and acted as the link between them and the larger companies, but "*project partners felt that Local Authority planning teams involved in this project struggled to fully understand the requirements of the project and the new technologies involved.*" [30]. There were also issues around the capabilities of the ALMO maintenance teams to manage the heat pumps. Although staff received training, issues still arose which required input from the manufacturers. The burden of responsibility and need to resource the relevant parties should be acknowledged and assessed in relation to the savings achieved, but also in relation to capacity building for the future electricity system. If a DR trial disrupts the existing distribution of skills, knowledge and action, then outcomes should include building knowledge and capacity as well as testing technologies.

6.3 Flexibility capital and fairness

Finally, we reflect on the relationship between flexibility and fairness. In the case of the NEDO trial, significantly more peak load reduction was achieved, but not to the benefit (nor to the obvious detriment) of participants. In fact, it may be wrong to view the heat pumps as contributing to participants' own flexibility capital at all. The technology is not owned by the tenants; they benefit from an effective and low-cost heating system, but the flexibility benefits are obtained by other parties. The answer to the question of whether such a 'contract' is fair in principle and practice is likely to be highly subjective. In the case of Energywise, the scheme was designed to ensure that no households could lose out financially, but the previous sections demonstrate how the pursuit of benefits from DR – a rebate in this case - can place uneven pressures and demands on different family members.

Currently the penalties associated with not being flexible are low or none, but this is changing as flexibility tariffs appear on the market. What can we infer about the fairness implications of the NEDO trial arrangement in a potentially more cost-reflective flexible future? In the case of the participants, even if it is acknowledged that they do not benefit from the flexibility capital afforded by the heat pumps themselves, they are at least protected from the expense or discomfort that would accompany a less flexible electric heating system. In the case of Energywise the trial was designed in such a way that participants could not lose out, regardless of their actions – but this should not necessarily be expected to be the case outside of a trial scenario.

Prospects for the groups focused on in these cases could therefore perhaps be characterised as neutral, with some risks. One risk would arise in the absence of bill protection mechanisms, resulting in a stronger financial imperative to economise socially-derived flexibility capital with the burden falling disproportionately on low income households who cannot afford smart home energy management systems. Another is the risk that automated control of heating strays into the realm of discomfort for occupants, as can sometimes be the case [32,33]. Even if these potential risks are mitigated, there remains very limited opportunity for stakeholders such as the participants in the trials discussed here to actually gain from a flexibility transition.

6. Conclusion

In this paper two real examples of domestic DR were presented which operationalise flexibility capital in very different ways. A cross-case comparison was used to examine how flexibility was created, by whom it was controlled and for whom it delivered value. This enabled some key considerations in the design of demand response to be highlighted.

Design choices to be considered include:

- Whether large demand response achieved through direct load control is more important than household participation and/or participant understanding;

- Conversely, whether a focus on participation will lead to an increase in domestic management, distributed unequally across household members;
- How much and what types of disruption are acceptable, the potential to use heat DR and existing energy storage in the building's thermal mass to decrease the level of disruption caused by DR, and to what extent doing this might increase disruption instead;
- Which parties should take responsibility and liability for different aspects of the demand response capability, and how should they be upskilled to do so.

These considerations are relevant to a number of stakeholders; the case studies in this paper illustrated that there are a number of new players in the DR market as well as new roles for traditional organisations. Local authorities now view energy services as a new sector they can use to deliver on existing social responsibilities such as fuel poverty reduction and possibly to generate new sources of income through an aggregator role. Housing providers are managing new energy technologies as well as maintaining their building stocks. Energy providers and technology companies can be the designers and drivers of DR schemes. Policy makers and regulators who create the conditions for DR markets must support all of these stakeholders whose objectives span from commercial to social.

Building on our experiences of providing social research to cross-disciplinary, experimental trials of demand response, we identify the need for energy social science to perform this critical evaluation and reflection. We present our approach and analysis in order to contribute to critical scholarship in the social science of energy and draw attention not only to the quantitative outcomes and value to the energy system delivered, but also the qualitative insights on questions of social equity. We demonstrate a critical comparative approach that can be used to gain new insight from published results of trials. The method used does not aim for generalisable statements about forms of DR, instead highlighting contextual factors that underpin the 'technical potential' of different forms of DR to understand the trade offs and the fairness implications. The comparison provides a framework for other researchers to critically reflect on how they might design a trial, or interpret the findings.

Finally, we suggest that as societal change becomes more recognised as key to driving the energy transition [41], research that contextualises quantitative energy system outcomes within the social realities that delivered these outcomes is increasingly urgent. This will help government, industry and the consumer understand what it takes to create the flexibility needed in the energy system.

References

[1] M.H. Albadi, E.F. El-Saadany, Demand Response in Electricity Markets: An Overview, in: 2007 IEEE Power Eng. Soc. Gen. Meet., IEEE, 2007: pp. 1–5. https://doi.org/10.1109/PES.2007.385728.
[2] EPSRC, Framework for Responsible Innovation, (n.d.).
[3] M. Mazzucato, Mission-oriented innovation policies: challenges and opportunities, Ind. Corp. Chang. 27 (2018) 803–815. https://doi.org/10.1093/icc/dty034.
[4] S. Bell, E. Judson, H. Bulkeley, G. Powells, K.A. Capova, D. Lynch, Sociality and electricity in the United Kingdom: The influence of household dynamics on everyday consumption, Energy Res. Soc. Sci. 9 (2015) 98–106. https://doi.org/10.1016/j.erss.2015.08.027.
[5] Y. Strengers, Smart Energy Technologies in Everyday Life, Palgrave Macmillan UK, London, 2013. https://doi.org/9780203108543.
[6] G. Powells, M.J. Fell, Flexibility capital and flexibility justice in smart energy systems, Energy Res. Soc. Sci. 54 (2019) 56–59. https://doi.org/10.1016/j.erss.2019.03.015.
[7] L. Nicholls, Y. Strengers, Peak demand and the 'family peak' period in Australia: Understanding practice (in)flexibility in households with children, Energy Res. Soc. Sci. 9 (2015) 116–124. https://doi.org/10.1016/j.erss.2015.08.018.
[8] A. Losi, P. Mancarella, A. Vicino, Socioeconomic Aspects of Demand Response, in: Integr. Demand Response Into Electr. Chain, John Wiley & Sons, Inc., Hoboken, NJ, USA, 2015: pp. 215–239. https://doi.org/10.1002/9781119245636.ch9.
[9] A. Haque, M. Nijhuis, G. Ye, P.H. Nguyen, F.W. Bliek, J.G. Slootweg, Integrating direct and indirect load control for congestion management in LV networks, in: IEEE Trans. Smart Grid 10, 2017: pp. 741–751.
[10] Frontier Economics, Sustainability First, Demand Side Response in the domestic sector - a literature review of major trials, (2012) 156. https://www.frontier-economics.com/documents/2013/10/frontier-report-demand-side-response-in-the-domestic-sector.pdf.

[11] US Department of Energy, Customer Acceptance, Retention, and Response to Time-Based Rates from the Consumer Behavior Studies, 2016.
[12] J. Stromback, C. Dromacque, M.H. Yassin, The potential of smart meter enabled programs to increase energy and systems efficiency: a mass pilot comparison, Helsinki, 2011.
[13] P. Calver, N. Simcock, Demand response and energy justice: A critical overview of ethical risks and opportunities within digital, decentralised, and decarbonised futures, Energy Policy. (2021).
[14] G. Whitaker, R. Wardle, C. Barteczko-Hibbert, P. Matthews, H. Bulkeley, G. Powells, Insight Report: Domestic Time of Use Tariff: A comparison of the time of use tariff trial to the baseline domestic profiles (No. CLNR-L093)., 2013.
[15] J. Schofield, Dynamic time-of-use electricity pricing for residential demand response: design and analysis of the Low Carbon London smart-metering trial, Doctoral Thesis, Imperial College London, 2015.
[16] UK Power Networks, Low Carbon London Project Close Down Report V.10., London, 2015.
[17] L. V. White, N.D. Sintov, Health and financial impacts of demand-side response measures differ across sociodemographic groups, Nat. Energy. 5 (2020) 50–60. https://doi.org/10.1038/s41560-019-0507-y.
[18] E. Sherwin, I. Azevedo, R. Meyer, Characterization of utility programs' enrollment by income and region, in: ECEEE SUMMER STUDY Proc., European council for an energy efficient economy, 2017.
[19] N. Moon, D. Rodgers, S. McHugh, Energy Market Investigation: A report for the Competition and Markets Authority, 2015.
[20] Big Sofa, Understanding the consumer experience of Dynamically Teleswitched (DTS) meters and tariffs, London, 2014.
[21] C. Milchram, R. Künneke, N. Doorn, G. van de Kaa, R. Hillerbrand, Designing for justice in electricity systems: A comparison of smart grid experiments in the Netherlands, Energy Policy. 147 (2020) 111720. https://doi.org/10.1016/j.enpol.2020.111720.
[22] G. Thomas, C. Demski, N. Pidgeon, Energy justice discourses in citizen deliberations on systems flexibility in the United Kingdom: Vulnerability, compensation and empowerment, Energy Res. Soc. Sci. 66 (2020) 101494. https://doi.org/10.1016/j.erss.2020.101494.
[23] G. Powells, M.J. Fell, Flexibility capital and flexibility justice in smart energy systems, Energy Res. Soc. Sci. 54 (2019) 56–59. https://doi.org/10.1016/j.erss.2019.03.015.
[24] J. Heaton, Reworking Qualitative Data, SAGE Publications Ltd, 1 Oliver's Yard, 55 City Road, London England EC1Y 1SP United Kingdom, 2004. https://doi.org/10.4135/9781849209878.
[25] B.K. Sovacool, J. Axsen, S. Sorrell, Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design, Energy Res. Soc. Sci. 45 (2018) 12–42. https://doi.org/10.1016/j.erss.2018.07.007.
[26] UK Power Networks, Vulnerable Customers & Energy Efficiency Project Close-Down Report, London, 2018.
[27] UK Power Networks, Vulnerable Customers & Energy Efficienc: SDRC 9.5 The energy shifting trial report, London, 2018.
[28] UK Power Networks, Vulnerable Customers and Energy Efficiency SDRC 9.1 Trial Design & Identification of Trial Participants, London, 2016.
[29] C. Johnson, Is demand side response a woman's work? Domestic labour and electricity shifting in low income homes in the United Kingdom, Energy Res. Soc. Sci. 68 (2020). https://doi.org/10.1016/j.erss.2020.101558.
[30] NEDO, Implementation Report for Smart Community Demonstration Project in Greater Manchester, UK, Manchester, 2017.
[31] Centre for Sustainable Energy, How much electricity am I using?, Bristol, 2013.
[32] T. Sweetnam, M. Fell, E. Oikonomou, T. Oreszczyn, Domestic demand-side response with heat pumps: controls and tariffs, Build. Res. Inf. 47 (2019) 344–361. https://doi.org/10.1080/09613218.2018.1442775.
[33] C. Hanmer, Flexibility of UK home heating demand: an exploration of reactions to algorithmic control, UCL, 2020.
[34] C. Johnson, Is demand side response a woman's work? Domestic labour and electricity shifting in low income homes in the United Kingdom, Energy Res. Soc. Sci. 68 (2020). https://doi.org/10.1016/j.erss.2020.101558.
[35] UK Power Networks, energywise: SDRC 9.5 The energy shifting trial report, London, 2018.
[36] P.J. Boait, D. Fan, A. Stafford, Performance and control of domestic ground-source heat pumps in retrofit installations, Energy Build. 43 (2011) 1968–1976. https://doi.org/10.1016/j.enbuild.2011.04.003.
[37] A. Owen, G. Mitchell, R. Unsworth, Reducing carbon, tackling fuel poverty: adoption and performance of air-source heat pumps in East Yorkshire, UK, Local Environ. 18 (2013) 817–833. https://doi.org/10.1080/13549839.2012.732050.
[38] N.M.A. Huijts, E.J.E. Molin, L. Steg, Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework, Renew. Sustain. Energy Rev. 16 (2012) 525–531.

https://doi.org/10.1016/j.rser.2011.08.018.
[39] M. Goulden, A. Spence, J. Wardman, C. Leygue, Differentiating 'the user' in DSR: Developing demand side response in advanced economies, Energy Policy. 122 (2018) 176–185. https://doi.org/10.1016/j.enpol.2018.07.013.
[40] UK Power Networks, Vulnerable Customers and Energy Efficiency Project Progress Report –July to December 2017, London, 2017.
[41] National Grid, Future Energy Scenarios 2020, Warwick, 2020.