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Eliciting Requirements for Demand Response Service Design to Households: A Pilot Study

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Abstract— Demand response has been discussed as one of the key means through which peak energy demand could be ameliorated. A wide variety of research and trial studies have been conducted on this topic. Yet, there has been no requirements elicitation exercise undertaken to explicitly state the requirements that a smart appliance automation service must address to be accepted by the households at large. This paper presents a pilot study on just such an exercise. We present the key themes from the pilot interview study. From these themes we identify several groups of requirements, such as need to retain ultimate appliance control (e.g., through manual overrides); need for discriminating between specific appliances and their contexts for automation; need to be able to associate personal meaning to the service participation process by setting own goals, etc.

I. Introduction

Demand side response can potentially be used to deliver a number of services, both to the household prosumers (i.e., households who have own generation equipment, and/or battery storage, and so generate as well as consume energy) and to the energy retailers/suppliers/utilities. A few examples of such services and their potential benefits to consumers are that:

- By shifting their consumption away from the peak demand time, the households would be able to use the same amount of energy at better total price (with variable pricing);
- By storing energy at the time of excess own generation and selling it to the grid at the peak demand time, the households could obtain additional income;
- By providing a (portion of) their battery storage as a generation reserve to a supplier, they could get additional income from frequency response services;
- By subscribing to automated demand curtailment services, the households could engage with supply/demand balancing services provided by the energy service providing utility/retailer, gaining yet another avenue of income.

Yet, currently the sign up to DSR service delivery is relatively low even from larger energy market participants, as noted in [1]:"DSR capacity was lost due to some aggregators achieving lower than expected sign-up of DSR". This is often motivated by risk, complexity of the service delivery, and lack of trust towards the DSR market [2].

Nevertheless, "there is strong evidence that automation or direct load control increases response, particularly for larger loads such as heating and air conditioning [2]. The main engagement strategies for the DSR services take up are:

- Economic benefits: appealing to cost saving potential;
- Environmental benefits: appealing to green credentials and CO2 savings;
- Customisation of product offerings: providing tailored products and services based on behavioural data of consumer segments;
- Simplification of energy use: ensuring customers are on board with and fully understand the product they are buying;
- Use of smart home technology brought into the consumers house for comfort and security purposes with DSR services tagged on at a later stage.

With the above in mind, this study aims to investigate the requirements that a DSR service needs to meet in order to gain acceptance by a wide range of households.

So far the main body of automation for DSR has focused on the service providers taking over the control of the household appliances for demand management. However, the contextual variability of the user population (e.g., baby in the family, shared vs. private space where potentially noisy appliances are located, etc.) and their willingness to relinquish control over various aspects of appliances, when subscribing to DSR service, are still not well understood.

The key question to be addressed by the present research is: *What requirements should an automated DSR service support in order to be positively received and adopted by the households at large?* To address this question, we have designed a qualitative study (outlined in section III). This paper presents the results of the pilot of this study and reports on the initial requirements for the usable automated DSR service (discussed in sections IV and V). The full study plan, which aims to both expand the present findings and validate them through an additional quantitative instrument, is outlined in section VI.

The present study has identified several groups of requirements (summarised in Table I), which are requirements for control over an automated DSR appliance (e.g., through an ability to manually overrides the DSR settings); requirements for discriminating between specific appliances and their contexts for automation; requirements for penalisation of and education via the DSR services.

The present study suggests that by better understanding and supporting the needs of the intended DSR service users (i.e., households), we would be able to compose a more

flexible, customisable, simple, and comfortable DSR service provision, which would foster the service uptake.

II. RELATED WORK

Related work on demand management has observed that the the the "public wants and expects change with regard to how energy is supplied, used and governed." [3] Yet, while some scenarios of automated appliance government are acceptable (eg., 78% of respondents accepted automatic turn off of TV from standby), the others are less so (e.g., only 30% of respondents accepted the idea of automatically turning off a fridge/freezer for short periods during the peak demand). Overall, the scenarios that allow householders some control are preferable and interventions that assist people in shifting their own energy use patterns are viewed positively. Yet, most elements of DSM are unfamiliar to the public and needed explaining [4], [3].

Several studies have focused on understanding the factors that affect energy consumption at home. For instance, Jones and colleagues [5] identified 62 factors that affect energy consumption in households from an extensive literature review. These factors were related to 3 key areas, the most often repeated in (several) studies are:

- Socio-economic factors: e.g., more occupants, teenagers and higher income and disposable income all contribute to significant increases in electricity consumption. The presence of children or elderly people and education levels show no conclusive effect.
- Building factors: e.g., age and size (number of rooms, bedrooms and floor area) all contribute to increased consumption as does electric heating, electric water heating and air conditioning.
- Appliance-related factors show a clear effect in increasing consumption: e.g., more appliances, desktop computer, tv, electric oven, refrigerator, dishwasher, tumble dryer and greater use of washing machines and dryers. Other appliance factors have been studied less or have inclusive results.

Boomsma et al [6] categorised consumption by contexts: morning, evening, regular, important, most energy consuming, summer or winter. Participants were surveyed on energy use in relation to context types of activity, energy saving strategies and perceptions of high energy consuming activities.

Kavousian and colleagues [7] suggest that the daily minima of consumption is explained by constant factors (e.g., house size, numbers and type of devices), whilst daily maxima relate to the number of occupants and high-consumption intermittent-use appliances. Here it is suggested that four groups of factors affecting energy use are: (i) external conditions (weather, location), (ii) physical characteristics of the building, (iii) appliance and (iv)occupant behaviour.

Others have studied the effectiveness of information provision to households on their energy consumption either through smart meters, or via in-house displays [8], [9], concluding that, by themselves, these are insufficient for motivating any action or change in energy consumption behaviours.

A study by Whitmarsh et al [10] notes that the ability of the households to change their behaviour in support of carbon reduction is limited, because carbon footprint (and respectively, energy consumption) is not a driving force in everyday behaviours even when individuals are knowledgeable and motivated to act. Gabe-Thomas and colleagues [9] concur that the fact as to how much energy an appliance consumes is not at the forefront of householder's consideration when utilising an appliance; instead the domestic practices take priority. As noted by Shove and Walker [11], energy consumption is a by-product of the activities of society; "demand and the means to consume constitute each other", where means to consume include such things as grids, power stations, networks, and devices with which end-users engage.

In summary, it is evident that energy consumption is intertwined with the habits and preferences of households, the stock and capability of their appliances, the physical properties of their dwellings, and the social and personal values and norms. Given that the problem is inherently multi-faceted [12], it is necessary to provide a solution that tackles as many facets of this problem as possible.

A. DSM Trials

Buryk and colleagues [13] worked on a 3-week trial to determine whether disclosing the environmental and system benefits of dynamic tariffs to residential customers could potentially increase their adoption. The trial included 160 residents in US and EU out of which 88 received information on environmental and systems benefits from dynamic tariff use, while the rest did not. The trial found that the respondents strongly preferred environmentally-friendly energy consumption and supply mix, and were willing to switch to a cleaner supply, even if it was up to 10% more costly. Additionally, the trial observed that in the US air conditioning has the highest potential for shifting demand during the summer, and in EU the electric heating has the highest shifting potential in winter.

Buchanan and colleagues [14] undertook a study of threats and opportunities on use of smart meters in the UK. They first ran a workshop to develop concepts for smart meter enabled services and then conducted focus groups to explore consumers perceptions of smart meters how smart meter data can be used to provide services. They considered 3 option: automation of appliance use, community rewards for disciplined use of appliances, and gamification as motivator for peak avoidance and use reduction. They found that automation was consistently the most preferred concept. Participants realised that the proposed system offered them different choices about if and when they would like the system to control their household appliances. Community reward scheme was not very liked, participants stated they would rather receive money off their energy bills than contribute toward paying for a collective benefit. Gamification was not popular either, as participants did not have the time to commit.

Customer experience of demand side response with smart appliances and heat pumps is studied in the trial by Capova and Lynch [15] for a small sample of houses in Durham. Here none of the participants believed that the direct control of the service provider over the appliances had any influence on decisions about when to do the laundry. All participants thought that they had not changed any of their previous washing regimes.

Energy Demand Research Project: Final Analysis [16] undertook a UK-wide trail (through four energy suppliers - EDF, E.ON, Scottish Power and SSE) to elicit impacts of various interventions into energy consumption behaviour (individually or in combination) between 2007 and 2010. While the trial's main focus was reducing domestic energy consumption, it also carried out a study on shifting energy use from periods of peak demand. Trial focused on evaluation of the effectiveness of such interventions as using a combination of smart meters and Real time displays, historical use feedback, comparison with other similar households, etc.

The trial observed that smaller households (1-2 people) were more likely to gain form the use shifting. The trial found more response to shifting load from peak period on the weekends rather than weekdays. Overall, the participants saved around 3%.

However, the trial found no reliable or persistent effect of either financial incentives to reduce energy consumption or general statements of commitment to reduce consumption.

III. INTERVIEW STUDY DESIGN

This paper reports on the results of a qualitative interview study on the requirements for automation of DSR and its acceptance by households.

The study design commenced with preparation of interview questions in a similar format to the studies from related work, but with a focus on the DSR design and automation requirements.

Two preliminary interviews were conducted to validate the clarity and relevance of the interview questions. Several new questions were added into the question set based on additional detail received from the validation answers. However, the main question set and interview structure overall was not altered greatly. This was used for the actual interview study.

The final interview question set consisted of 3 sections. The first section aimed to learn the interviewee's daily routines, the times at which they utilise various appliances, what drives the actions of the smart appliance users. The second section focused on automation and the attitudes of the interviewees towards various benefits of automated DSR systems. The last section introduced the idea of automated DSR service and explored participants' motivations behind potentially using such services. It also enquired about their attitude to energy consumption data sharing.

Given that the aim of this work was to carry out a pilot study, we used the *convenience sampling* method [17], recruiting easily accessible participants quickly and free of cost. This, clearly, come at the expense of generalisability of the findings, as the validity of the results could be threatened by as the sample could be biased (given that this sample is not carefully selected to be representative of the population at large). Yet, we consider that this sampling technique is suitable for the piloting of our study [17], and the full-scale interview will use a probabilistic sampling technique to mitigate this threat to validity.

Each interviewee was given a participant information sheet to read prior to their interview to gain an understanding of the topic and scope of the questions to be discussed.

A. Data Collection and Analysis

Data was collected through face to face interviews. We interviewed 7 individuals: 4 male (Paul, Jack, Callum, Yash) and 3 female (Carol, Tilly, Nema). The interviewees presented a mix of professionals (a lecturer, a researcher, an investment banker, a medical practice manager) and students. All participants were fluent in English.

All interviewees live in the UK and use common (smart) household appliances which are relevant to this study. The interviewees live with family or in shared houses/flats of 2-6 people (i.e., there are no single household occupants here). This sample was chosen with the intent to explore the different constraints that cohabitants face when using appliances. The interviewees had different motivations for when and how to use appliances depending on their career or family situation etc. For example, one of our interviewees has a toddler, another has long, unusual working hours.

All interviews were recorded and analysed as discussed below.

B. Data Analysis

To analyse the data, a form of Grounded Theory analysis [18], [19] was used, where the peoples experience on appliance use was researched, and theories generated about how these experiences can relate to informing the automated DSR service design. These theories are formulated as initial requirements (summarised in Table I and discussed in section V) that a demand response automation service should support.

To start with, the interview recordings were used to determine different categories of concerns discussed in the interview data. These categories were then coded. A constant comparative analysis was done to ensure consistency in coding of the data across all 7 interviews.

This was complemented by analysis of how the various code categories relate to one another (the so-called axial coding process) which resulted in a sub-categorisations and generalisations of several code categories (discussed in section IV). Finally, these categories are reviewed from the perspective of DSR automation service design, and a grouping of requirements, which are contributed to by these primary code categories, was formed (discussed in section V).

IV. PILOT STUDY FINDINGS

Factors Influencing Appliance Use: The pilot study confirms previous research [11], [9], [10] findings that factors

such as cost of energy or time of use do not concern the individuals when going about their daily lives. As one respondent (Tilly) noted, "I normally don't use my brain and do quick wash". The way that appliances are used is driven by such factors as:

- work/job timetable (i.e., when work starts and stops)
- weekend vs weekday;
- needs of the family members (e.g., young children, playing sport);
- preferences of the individuals;
- presence of visitors in the house (e.g., parties, guests overnight);
- preferences of other inhabitants in a shared house;
- seasonal and weather factors;
- constraints and capabilities of the appliances

All these factors have already been noted as relevant in previous research.

Green Traits: We also observe that, within their daily routines, many of the respondents had *built-in traits of green behaviour, especially where the appliances afforded automated support* for this. For instance, when discussing the last use of their washing machines and dryers, some respondents (Tilly, Jack, Yash) underlined that they choose eco-friendly settings where possible, for example:

- Tilly uses an "eco-friendly setting and quicker time",
- Yash says: "I try to be as eco-friendly as possible whilst making sure my clothes get properly cleaned,. So I try to put the settings at 40 or eco-friendly which is at 30....".

Per-Appliance Flexibility: When asked about changing the time of use of appliances, the respondents indicated that while time of use of some appliances can be shifted (e.g., for washing machines and dryers), for others the change will not be acceptable (e.g., for shower, oven, TV). The per-appliance flexibility and constraints will also be very specific to each individual's preferences and circumstances. For instance, Jack notes that "Washing machine, if you could put your load in, turn it on and then whenever the system deems it to be most efficient to run it at that point, then it'll run it. ... TV is harder because sometimes it's time-critical, so programs are on at certain times... but for streaming, I'm more than happy to change times." So, while Jack sees TV use time to be flexible, there are clearly some programs (e.g., the World Cup games) where real-time viewing is essential to him.

Contextual Factors: As noted before, whether the time of use of an appliance is flexible will largely be influenced by how the appliance interrelates with the above listed 'use factors'. For instance, while Tilly is happy to shift the time of washing machine use, she lives in a shared house and she notes that "The washing machine may be used by others, and can be loud, so can't do it when everyone is sleeping ... oven and shower - you have to wait for it to be free". Similarly, Yash points out that "Often we have to be aware of not having a loud washing machine/dryer running if we have guests overnight or if we are hosting guests during the day on Saturday".

Automation for Cost Reduction: The majority of respondents confirmed that they would be willing to shift energy consumption activities for some appliances to different times if they were able to reduce costs. However, the time shifting must still fit the contextual and per-appliance constraints (e.g., Tilly would shift use of " Oven and washing machine, but not shower", while Paul will shift if "it doesn't disturb us in the night"). However, Callum was clear that "financial benefits won't influence too much", as he does not see the energy costs to be too high to start with.

Amenability to Automation: Most respondents were generally comfortable with the idea of appliance automation for DSR, except for Carol who said she was "not comfortable at all" about the idea of automation. Yet, all interviewees underlined the necessity of *retaining control* over the automated appliances primarily in terms of ability to override the automation through manual controls (e.g., Paul: "as long as you can manually override it" Nema: " ... I have some control over it"). Another very relevant feature of automation expressed here is the *accountability of the automated system*. For instance, Tilly would like to see "summaries of how much you are saving", Nema wants to know "what the system is [and is doing]", Yash wants to "see exactly what's happening".

Drivers to Automation: The main drivers for automation are *cost saving*, carbon *footprint reduction*, *traceability of consumption*, and *potential convenience*. For instance, with respect to traceability, Yash notes that "I would like to see stats on exactly what we're using and how", while Nema states that she would "like to have control over how much money I'm spending/how many lots I'm doing per day, and they [interface to the automated system] provide [information on] at what times of the day saves me more money....". Nema thinks she will "feel good" about herself as she will be "more eco-friendly so I'm doing my bit for the world". Interestingly, all other interviewees too agree that they will be more likely to engage with automation if their carbon footprint for the automation activity was directly visible, and quantifiable. Paul, for instance, notes that he is "more likely to do things if it had and environmental impact". Paul also notes that automation could be more convenient as, for instance, the "automated heating system [is] more responsive".

It is worth noting that though cost saving was pointed to as a key driver by most interviewees, they also said that the cost saving must be significant to motivate joining the automation service, ranging from a minimum of £4 (for Yash) to double figures e.g., £10 for Tilly. Furthermore, Yash adds: "If I'm having to change my entire routine, it would need to be at least £10-15 per month". Similarly Jack expects to get savings of at least 1/2 to 2/3 of the current energy costs.

Obstacles to Automation: To the present interviewees, the obstacles to automation come primarily from expected *loss of convenience* (e.g., Paul), *loss of control* (e.g., Tilly "if it is fully automated and only the energy supplier can control it"), *potential noise* at undesirable times (e.g., at night, as per Carol " noise at night for neighbours"), *inflexibility* (e.g., Jack "a large inconvenience of needing to use that appliance

Group	Requirement
Control	R1. Manual Override
	R2. Data Sharing
	R3. Tractability of Consumption
Per-Device Automation	R4. Selective, per-device automation
	R5.Individual device context and profile
Personalisation	R6. Set own goals
	R7. Define preferences per context, day, time
	R8. Maintain comfort
Default Participation	R9. Opt out vs opt in
	R10. Social interconnection
Education	R11. Inform on gains and losses
	R12. Educate on contributions

and not being able to use.... Things turning on when it's not appropriate for them to turn on when people are sleeping..."), potential *complexity and lack of usability* (e.g., Paul "not having a straightforward system"), *fears for security* (e.g., Tilly "security if working wirelessly"), loss of routines (e.g., Yash notes "there may be conflicts within the flat because we have to change our routines..."), *low return compared to expectations* (Yash: "it may not save us as much money as we want it to so it's not worthwhile").

Social Compliance: The majority of the respondents corroborated the notion of peer/community pressure, stating that if their neighbours/friends were to sign up to the automated service, they are likely to sign up too, particularly if the service had been "given good reviews" (Tilly), and been "tried and tested" (Jack).

Data Privacy: All participants but two expressed concern about sharing their data on appliance use with their energy providers, stating that they "Don't trust energy providers". Nema stated that "With all the data frauds that we see happening around us, I would be giving them the very limited amount of data that is required. I wouldn't give them details about my lifestyle for example". Only Tilly and Yash were willing to share this data, if anonymised, with their energy providers.

V. CHARACTERISING INITIAL AUTOMATED DSM SERVICE REQUIREMENTS

Drawing on the above presented interview results, we set to address our initial research question: What requirements should a DSR service support in order for it to foster comfort for the users and acceptance by a wide range of households? The themes from the interview responses are integrated into coherent topics of specific requirements, as summarised in Table I and further discussed below.

Control and fear of control loss have been noted as the key concerns by the interviewees, and noted as a key obstacles to automation. The interviewees are clear on the need for manual override option for all automation service (R1 in Tab. I) so that they remain in immediate control of the equipment, even if they choose to join an automation service. This is understandable, as the interviewees wish to be able to deviate from the agreed service/behaviour if the circumstances are pressing (e.g., need to use dishwasher immediately when entertaining guests, as noted by Yash).

Another key concern is control over access to one's data (R2 in Tab. I: respondents wish to be able to allow or prevent access as they see fit.

Finally, some of respondents are also interested in having control over their own consumption behaviour, for which they want to be able to see their consumption information (R3 in Tab.I).

Per-Appliance vs Uniform Automation is another notable group or requirements. As each appliance is used within its related practices, the respondents were unwilling to allow interference with the practices that they give particular importance (e.g., having a shower in the morning). Yet, they were willing to allow change to the device use which were non-critical to them (e.g., starting washing machine later in the day). Consequently, unwillingness to allow shifting use of a particular appliance may prevent participation in the automation service altogether, if this service applies to all devices at the same time. Therefore, providing automation service per individual device (R4 in Tab.I) will likely foster participation in the service uptake. However, we also note that the way that an appliance is used and/or prioritised differs between households, and the same automation service for a device would not be acceptable to all households. For instance, while one household may refuse to shift shower use from morning demand peak, the other may not. Thus, the automation service providers should allow not only per-device service, but also allow contextualisation of the device use (R5 in Tab.I).

Personalisation requirements here relate to the ways that an individual finds a meaningful ways in engaging with the automation service. Some individuals automate for financial reasons, others for environmental, others for community support, etc. Thus, the participants should be able to set own goals (R6 in Tab.I) as to why they join the automation service and what they wish to achieve (e.g., save £4 per month, or reduce CO2 impact by 5% per month, etc.). They should also be able to customise the context of the automation service (R7 in Tab.I; context option availability was already discussed in R5). Finally, households should also be able to maintain comfortable environment (R8 in Tab.I) within their homes, else the automation service will not be taken up. Though what "comfort" means specifically within the appliance use and automation context, is still to be researched.

Default Participation requirements are drawn from the past research and practice findings that the individuals more often than not keep to the default settings. In other words, if the households are assumed to participate in the automation service by default, they are more likely to remain and participate in the service (though they will be free to leave the automation), then if they were asked to join explicitly. Thus, should the automation service be offered by a utility,

it would be more efficient to notify the households about the start of the service and allow those unwilling to participate to opt out (R9 in Tab.I).

Additionally, as most respondents noted that engagement through feedback and interaction with friends and neighbours would stimulate their own participation, the automation service provider should support such engagement and feedback mechanisms as part of the service delivery (R10 in Tab.I).

Education requirements emerge from the wish of the respondents to know what they gain or lose by participating in the automation service (R11 in Tab.I), and their desire to learn more about energy, environment, and financial consequences of their choices (R12 in Tab.I). The educational aspect of the information provision can be linked to the personal goals' (R6) aspect of the automation as well.

Thus, we have elicited the initial (theorised) set of requirements that the demand response automation service should support, if it is to be acceptable by a wide range of households. Yet, the relevance of these requirements outside of the pilot study sample remains to be validated.

VI. Conclusions and Future Work

The present pilot study provided a valuable insight into the requirements that the households hold with respect to the Demand Side Response and automation service for energy consuming devices, as discussed in section IV. However, the pilot study was undertaken with 7 respondents only, and provides a very initial insight into the DSR service requirements.

To adhere to the full Grounded Theory analysis approach, which we adopted and discussed in section III-B, we would need to undertake the process of *discriminant sampling*, whereby a new group of participants (similar to the original participants) are recruited and the same interview is conducted with these new participants to test whether the overall theories hold for the new set. This is precisely what we plan to do in the ongoing further work. To validate/refute and expand on these initial results, a larger study is underway. This study will:

1) undertake further interviewers (with discriminant sampling) in order to collect additional data on the above discussed requirements, and, possibly, identify new groups or requirements. We aim to reach some 20-30 additional respondents;

2) carry out a survey (upon interview data analysis) to validate the interview findings for the population at large.

It is intended that the findings from this research will form the grounds for an actual DSR service design and trial.

VII. ACKNOWLEDGEMENTS

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