

# Householders' readiness for demand-side response: A qualitative study of how domestic tasks might be shifted in time

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**ABSTRACT:** Domestic demand-side response (DSR) involves having householders shift energy-consuming behaviours forwards or backwards in time to avoid peak-demand periods. Time of Use tariffs, which vary the cost of energy depending on when it is used, are a proposed mechanism for DSR. However, we do not know which behaviours, if any, are amenable to being brought forward or postponed, nor what information people would need to do this. Here we presented people with hypothetical variable financial costs and, for the first time, carbon costs for future energy consumption. People's think-aloud decisions about when they would perform consumptive activities were qualitatively analysed. We show that non-daily high-consumption activities (e.g., ironing, vacuuming) are perceived as moveable in response to price changes or, notably, information about environmental consequences; but barriers to moving other activities, even in the face of higher costs or environmental harm, include household dynamics (difficulties negotiating consumption across cohabitants), social roles, community living (not wishing to disturb neighbours), lack of energy literacy and the routine nature of many tasks. This study provides a framework for understanding which behaviours might or might not be shifted and what guidance and information may be needed by householders if tariffs are to provide effective DSR.

**KEYWORDS:** Demand-side response; energy literacy; households; social practices

Traditionally, variations in consumer demand over time have been taken as given and it has been the role of electricity generators and distributors to ensure that supply keeps up with demand (Ofgem, 2016). To avoid supply interruptions, the generation and distribution system must be scaled for peak demand. This means the network is, in effect, over-engineered much of the time, with financial costs for its operators. Moreover, end-user demand variations have pollution and carbon emission implications. In many countries, it is the more inefficient and polluting coal and gas power stations that are brought online at peak times (Goater, 2014) – an issue exacerbated when weather means the ability to generate from lower-carbon sources like solar or wind is low.

However, the relationship between electricity providers and consumers is set to undergo a sea-change (Fell, Nicolson, Huebner & Shipworth, 2015). This is thanks to the likely uptake of high-demand appliances like electric vehicles (Walker, Kennedy, Martin & Rice, 2016) and heat pumps; international targets for carbon and pollution reduction and a concomitant increased use of (inherently intermittent) renewable energy; the replacement of aging energy infrastructure (DECC, 2012); and the roll-out of smart metering in countries such as the UK and Ireland (Goater, 2014). Smart metering is interesting as it permits providers to set higher prices

at peak times and lower prices when demand subsides – perhaps even in real time. Such Time of Use (ToU) tariffs might thus provide an economic mechanism for demand-side response (DSR) – modifying end-user consumption – by incentivising the rescheduling of energy consuming activities and, thereby, helping smooth contours in demand. As domestic consumption accounts for over a quarter of UK energy use and carbon emissions (Palmer & Cooper, 2013), successful domestic DSR towards periods of lower-carbon and lower-pollution generation could bring substantial environmental benefits (Hamidi, Li, & Robinson, 2009) as well as economic benefits through reducing the need for network investment.

Trials of ToU tariffs so far have found relatively modest demand-side response. Faruqui and Sergici (2010) reviewed 15 trials, mostly using realistic three-step pricing (peak, off-peak and shoulder), and suggested reductions in peak consumption of around 3-6%. This fits closely with the 4.2% reduction estimated by Sæle and Grande (2011) after a Norwegian trial. When even people who have elected to take part in pricing trials make such limited shifts, it is clear there are substantial barriers to behaviour change that need to be better understood if DSR of more than a few percent is to be achieved.

These barriers become particularly pressing when we realise there might be considerable public appetite for DSR. A 2015 survey (Spence, Demski, Butler, Parkhill, & Pidgeon, 2015) suggested that many among the UK public are intrigued by the idea of ToU tariffs and would welcome such a system (e.g., 79% of respondents said they would be willing to spend more time thinking about electricity use). Financial savings and environmental concern appeared to be particular pulls towards such pricing.

The two key unknowns that need to be tackled right now are: (a) the policy and privacy issues surrounding the smart meter monitoring necessary for ToU tariffs (Spence et al., 2015) and (b), what social and psychological mechanisms would be involved in people responding to ToU tariffs (Hamidi et al., 2009; Nicholls & Strengers, 2015a). This latter issue is our focus here. The main work to understand ToU response so far comes from Nicholls and Strengers (2015a, 2015b), who interviewed and surveyed Australian parents about weekday on-peak activities specifically. They suggested family-based routines surrounding childcare presented a serious challenge to peak-time DSR. As a result, Nicholls and Strengers drew a pessimistic picture of ToU tariffs, suggesting they are unlikely substantially to influence peak demand and might lead to inequitable effects on lower-income families. Arguably, however, while Nicholls and Strengers's focus on caregivers locked into inflexible weekday routines is understandable, it might have made their remit narrow and their findings something of a worst-case scenario.

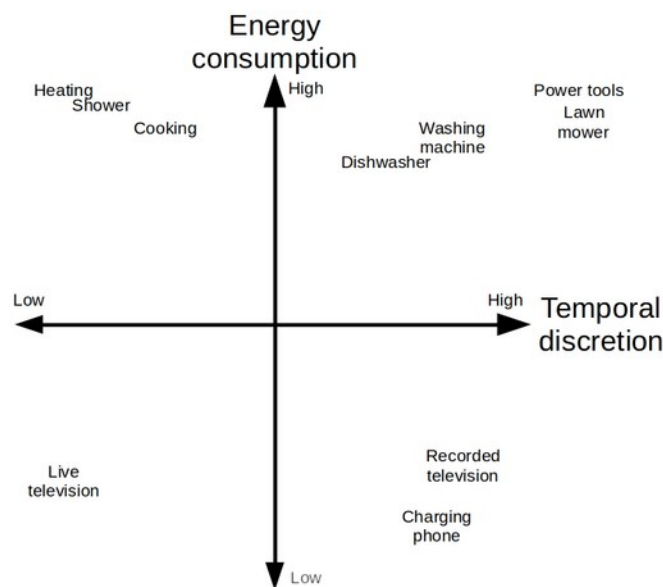
In this paper, then, we took a much broader and more taxonomic approach to how consumptive behaviours might respond to ToU tariffs. With a more general population, and without introducing specific constraints like childcare or a specific focus on peak hours, we evaluated whether or not behaviours are seen as moveable in time, why some behaviours might be seen as more or less flexible than others, and what information householders might need if they are to respond to ToU information.

We tested ToU information that described variations over time in price and, for the first time, carbon cost. Carbon cost was added for two reasons. First, we suggest in future that householders could (and should) be informed about the likely environmental consequences of their future energy consumption. Basic knowledge about where a country's renewable

generation is located means weather forecasts could feed into real-time predictions about solar or wind generation over the next one or two days, thereby informing householders about the probable carbon cost of their future electricity. Second, Spence et al. (2015) suggested environmental concern might be a key driver for ToU uptake. A householder motivated by environmental factors is likely to want exactly the sort of carbon forecast we envisage. Plausibly, high or low future environmental costs might be a motivator even in affluent households where variable monetary costs are not sufficient to change consumption.

When developing this study, the framework we initially used for thinking about domestic DSR was a simple two-dimensional model (illustrated in Figure 1 with a set of representative consumptive behaviours, some of which we later explored in the study to be reported). This illustrates how it is the top-right quadrant, representing high-energy behaviours perceived as amenable to rescheduling, that should logically be the optimal target for DSR. Given this model identifies the category of behaviours that should most change, we were interested in whether its two dimensions would emerge when people made decisions in the light of ToU information, and whether there might be other dimensions that we had omitted. It was therefore necessary to apply a qualitative methodology to allow people's perceptions to reveal themselves, rather than, say, a survey methodology which might have prompted participants to agree with propositions about which behaviours they would shift, in a way not representative of how they might really think when making DSR decisions in vivo (Thomas, Walker & Musselwhite, 2014).

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**METHODS**

**Participants**

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Thirty-three people participated, 28 of whom (85%) were personally responsible for making sure energy bills were paid in their home. Sixteen participants (49%) were male and 17 (51%) were female. Age was measured using categories: 14 participants (42%) were between 18 and 34, 17 participants (52%) were between 35 and 54 and the remaining 2 participants (6%) were 65-74 years. Income was also measured using categories. Ten participants (30%) earned under £12,000

per annum, 15 participants (46%) earned between £20,000 and £50,000 and 8 (24%) earned £50,000 or over. Participants' households had an average of 2.15 adults (range = 1 to 5, mode = 2). Ten participants (30%) had children. The maximum number of children per household was 2. Participants had resided in their homes for between 1 month and 24 years ( $M = 65.88$  months or approximately 5.5 years,  $SD = 75.55$  months). Seven participants were buying their home with a mortgage (21%), 9 (27%) owned their home outright and 14 (42%) were in private rented accommodation. Two participants lived in local authority or housing association accommodation. One participant selected the "other" housing category. Nine participants lived in terraced housing (27%), 11 (33%) participants lived in detached or semi-detached housing and 13 (39%) lived in either a flat or apartment.

## Materials

The study used 4 ToU tariffs, each printed as an image onto a sheet of A4 paper. Each of the images used a line to describe how the financial or carbon costs of energy varied over a 48-hour period (Figure 2). The displays were as follows:

A: Flat Rate Tariff: energy cost is constant over time (this is what most UK people currently experience). This display showed a constant horizontal line at a cost of 10 pence per unit.

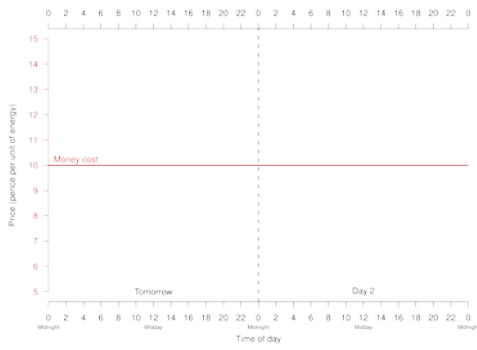
B: Two-tier tariff, modelled after the UK Economy 7 system. Prices are off-peak at night (7.2 pence per unit, from 21:00 to 06:00) and peak during the day (12.2 pence per unit). The graph therefore showed two simple blocks each day.

C: Three-tier tariff. This was based on a model described by Li et al. (2016) and had three price bands. Peak times (12 pence per unit) were from 16:00 until 18:00, shoulder times (9 pence per unit) were 06:00 – 14:00 and 19:00 – 20:00. The remaining times were all off-peak (7.2 pence per unit – see Figure 2).

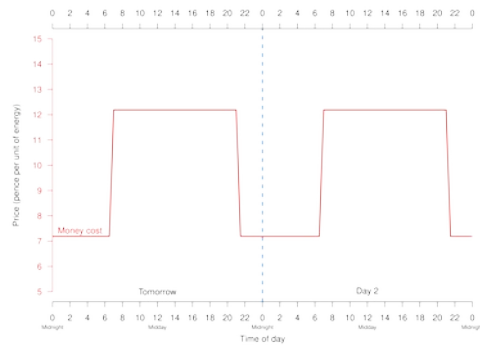
D: Carbon Cost only over 48 hours. The carbon information display we used – as shown in Figure 2 – simulated a situation whereby the next 24 hours' electricity generation would be carbon-intensive but the following 24 hours after that would be lower carbon (such a circumstance is plausible in a wind-generation country like the UK or Ireland, where windy weather might be forecast after a day of still weather).

E: The final display consisted of displays C and D – that is, the two graphs shown in Figure 2 – overlaid. This display therefore simultaneously presented financial and carbon information

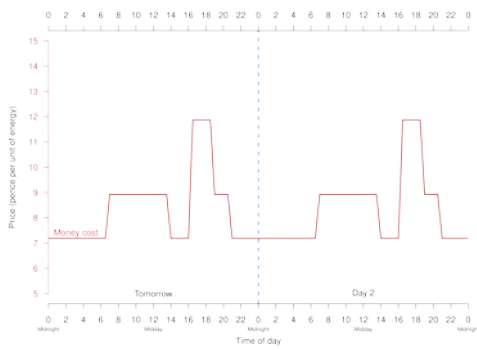
A set of transparent overlays showed different types of household appliances and their relative energy consumption (Figure 3). The participants' task was to place these overlays onto the tariff sheets to show when (if at all) they would choose to perform each behaviour. The full set of activities were: washing machine, television, dishwasher, tumble dryer, shower, oven, kettle, vacuum cleaning, ironing, hair dryer, [electric] lawn mower, microwave, recharging phone/tablet, and recharging e-reader.



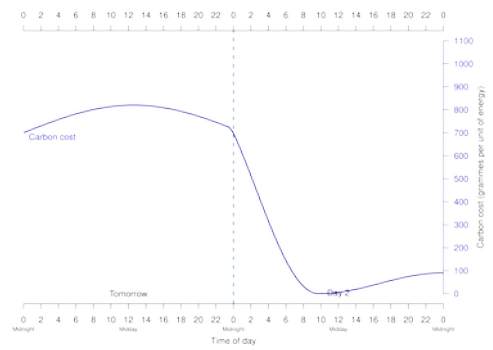
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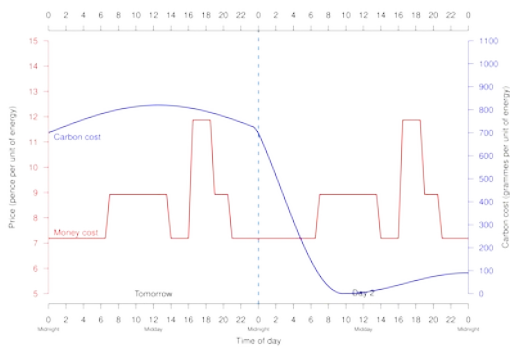
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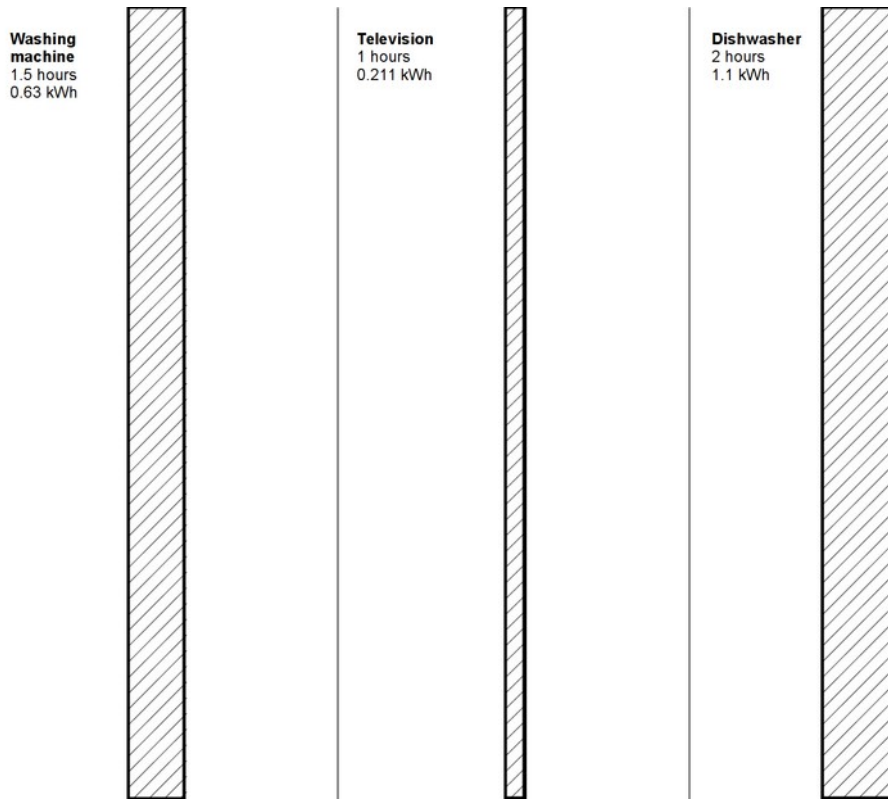
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Figure 2 - Examples of financial, carbon and joint Time of Use tariff displays





**Figure 3 - Three of the task transparencies that participants placed onto the displays shown in Figure 2 to indicate when they would choose to perform tasks. Transparencies were printed to scale so that the width of each task bar matched the same length of time on the time of use display.**

### **Procedure**

Participants were tested individually. They were first asked to imagine a 'typical' weekday in their household (this was done using the flat rate tariff) and then to imagine how (if at all) a typical day might be influenced by being subscribed to a ToU tariff. Each participant was provided with the full set of task transparencies and then the tariff sheets (Figure 2), one at a time in random order. For each tariff sheet, participants were asked to place the task transparencies on the sheet according to when they would be likely to perform the task. Participants were instructed to talk the experimenter through their decision-making while completing the tasks. In addition to being asked about a 'typical' weekday, participants were also asked whether their behaviours would be likely to differ at weekends.

Cognitive-style interviewing techniques were used with participants talking the interviewer through their reasoning processes while completing the task (Trickett & Trafton, 2009). The interviews were audio recorded and transcribed verbatim. A Grounded Theory-style approach was adopted with transcripts being read a number of times to build familiarity with the text (Glaser, 1978; Strauss & Corbin, 1990). Following this transcripts were coded line by line, with

emerging categories undergoing a process of constant comparison until new data only supported previously identified concepts (theoretical saturation).

After this test, participants completed the demographic questionnaires described in the previous section.

## RESULTS

We break the analysis into three sections: (1) a summary of responses to the various prototype tariffs, (2) facilitators and barriers to shifting the time of consumption, and (3) strategies for responding to time-of-use tariffs to minimise cost. Qualitative findings are presented thematically within each section. A sample of participant quotations has been provided to give the reader a flavour of how the themes arose from the data.

### Overall responses to prototype time-of-use tariffs

We begin with a brief summary of how the new tariffs were viewed. Note that the carbon-only tariff is omitted below as, owing to a testing error, only 11 participants were tested on this. However, people's responses to carbon information more generally can still be seen in their discussion of the combined money-carbon tariff.

#### *Two-tier tariff*

This tariff – which emulated the main ToU tariff available in the UK right now, “Economy 7” – had just two price bands: a high-cost peak during the day and a low-cost off-peak from 21:00 to 06:00. The tariff was widely seen as overly inflexible, with participants arguing that it was infeasible to undertake many activities at night. For example, vacuuming or doing laundry before 06:00 would disturb other household members or neighbours. Furthermore, even where undertaking the tasks would not be antisocial, the need to sleep meant undertaking tasks before 06:00 was generally seen as undesirable.

A few participants were, however, more positive about moving tasks to after 21:00 (although this generally did not extend to any likelihood of people postponing the preparation of evening meals this far):

*I think for [the] oven I might just have to bite the bullet and just say it's going to happen at eight o'clock [...] obviously you want to save energy and save money but there's only so much you can do when your stomach is rumbling and you need proper food. P07.*

#### *Three-tier tariff*

This tariff was based on a model described by Li et al. (2016) and had three price bands. Peak times were from 16:00 until 19:00, shoulder times were 06:00 – 14:00 and 19:00 – 20:00. The remaining times were all off-peak (Figure 2).



Participants generally said this tariff was likely to change when they used electricity. The drop in price at 14:00 incentivised having a later lunch (even if only at weekends), which in turn enabled people to plan to have their main meal slightly later, when prices were again lower. Participants also planned to use the off-peak period of 14:00 – 16:00 to undertake household tasks such as laundry and vacuuming, which were high consumption and which risked disturbing neighbours if done too early or late in the day.

*I'd probably push my food back, I'd wait until after eight when it's a little bit cheaper on both days, just have lunch later or something. P05*

Having fully off-peak electricity prices at night suited a number of tasks, in particular charging devices with batteries:

*I just fit the everyday consumption either before 07:00 or after 21:00 if it's possible – like [my] hoist, wheelchair, iPad ... What else? My shower can be taken after 21:00 and hairdryer will be used after 21:00. P22.*

The willingness to shift activities to after 21:00 (as in the final quote above) is in striking contrast to the two-tier tariff, for which participants showed marked reluctance to consider moving activities to exactly the same slot. This different treatment of the same timeslot suggests the greater variety of the three-tier tariff might be perceived as an attempt to fit people's lives, unlike the extreme simplicity of the two-tier tariff.

#### *Three-tier tariff with added carbon information*

One of the displays showed the three-tier tariff discussed above but with the addition of a line showing the carbon intensity of the electricity over 48 hours (the two displays in Figure 2, overlaid). Specifically, the carbon information display we used – as shown in Figure 2 – simulated a situation whereby the next 24 hours' electricity generation would be carbon-intensive but the following 24 hours after that would be lower carbon (such a circumstance is plausible in a wind-generation country like the UK or Ireland, where windy weather might be forecast after a day of still weather). This introduced to participants a situation in which, assuming carbon saving had any motivation to them, they might for the first time have to think about time-shifting over more than a diurnal cycle.

This display presented a dilemma for participants, insofar as carbon cost and financial cost did not necessarily correlate. Participants, weighing up both on the financial cost and environmental cost, demonstrated three categories of response. The dominant response was explicitly to compromise between financial and carbon costs, typically by moving intensive non-daily tasks to the lower carbon day.

*[A]s a sort of smart person I would want to try go half way in between [...] for instance, if you know that on day two you're going to have lower emissions and you know that your electricity costs the same as day one [...] you'd put things off until the next day if you could. So, things like putting on a load of washing or, you know, cooking a really big meal [...] if you had an electric oven. P26.*

The other responses seen in the data were to reduce consumption overall on carbon intensive days and to ignore carbon information and focus on financial saving. An example of a participant considering the former strategy would be:

*[T]rying to cut it down. I wouldn't mind it being a little bit more unpleasant for me in terms of if it's saving the environment a bit more. Definitely. P27.*

An example of somebody considering the latter strategy would be:

*Well you would go for the low price. You definitely wouldn't use it at the high price. P24.*

### Facilitators and barriers for time-shifting

We now look at the characteristics of household activities that were associated with those activities being described as easy or difficult to move in time in response to tariff signals.

#### *Frequency and duration of activities (mentioned by 69% of participants)*

The clearest topic arising in this study was the distinction between tasks repeated daily and tasks performed less frequently. This was discussed when considering both financial and carbon information. Daily tasks included making hot meals and drinks, showering and watching television. Participants saw all daily tasks as essential – no daily task from this set was seen as a luxury – and participants were only willing to make relatively minor adjustments (i.e., by a matter of hours) to the scheduling of these tasks:

*Okay, so our kettle usage would not change dramatically but I think we could avoid using it in that slot there. P13.*

*I'd wait until [21:00] to shower and then dry my hair quickly afterwards. P07.*

In contrast, non-daily tasks were perceived as being moveable by a matter of days rather than hours in response to ToU tariffs. Such tasks included ironing, laundry (washing and tumble drying) and the use of dishwashers.

*I could switch laundry or ironing those things until the next day [...] but not the rest because it's daily living. P23.*

*I guess the stuff we do every day would stay the same but the [other] things we can choose whether to do it a bit more. P00.*

Some tasks were seen specifically as weekend jobs (e.g., mowing the lawn), and weekends emerged as particularly important for those participants who worked Monday to Friday:

*We are more flexible on a weekend. That's the only time when we can be flexible really. P28 and P29, joint interview.*

*Things like washing clothes and vacuuming is [sic] a weekend job. P14.*

This tendency to link high-consumption appliances with high-discretion tasks is useful as it suggests the key top-right quadrant of Figure 1 might have some psychological reality to people.

Another encouraging idea to emerge from the data was that participants were often aware that higher-consumption appliances like washing machines, tumble dryers and dishwashers have a level of automation which can facilitate time-shifting:

*Tumble drying [...] dishwasher, and washing machine because they are the robots. P10.*

A second important factor in participants' decisions on whether to change the timings of electricity use was the duration of tasks. Recent research has shown that many people intuitively reason that tasks that happen quickly must use only small amounts of energy (van den Broek and Walker, 2019a, 2019b) – perhaps reflecting some confusion about how to integrate the length of a task with how often it is performed. A similar issue arose in this study, where participants were generally not amenable to the idea of rescheduling tasks such as showers or using the kettle specifically because they were short:

*I brew the kettle and it's only four minutes so I feel like that's less time, does that make sense? So it doesn't really matter if it's a little more expensive because I'm not doing it too long. P05.*

In the case of tasks where appliances needed to be used for longer time periods, participants also factored in the time required to conduct related tasks. For example, if participants planned to do laundry, they also factored in the time required for emptying the washing machine and the method and time required for drying the clothes. As such, whether moving the task was actually seen as feasible was not purely a product of its energy-consuming component.

#### *Food and Health (mentioned by 42% of participants)*

Having meals at regular times each day was seen as necessary. Meal times were based on household routines (e.g., when people return from work, school and bedtimes for children). Participants tended to simply state that they had got used to eating at certain times, that those were the times where when they would (as a result of this familiarity) be hungry, and that they would as a consequence not be amenable to making changes:

*I don't think I'd be willing to move my mealtimes back [...] I like to have my food at the same time. P05*

*It's not something we would change, regardless of the price. P09.*

In short, in relation to mealtimes, more rigid routines were viewed as necessary.

A small number of participants (9%) raised health related concerns about moving meal times to later in the day when electricity prices were lower:

*I would maybe try and delay meal times a little bit – say 7 PM to 8 is actually quite bad for your digestion I think it's actually quite bad to eat that late. P27.*

These results hint that cultural factors and shared beliefs may be a potentially serious barrier to time shifting. The UK participants here often constructed changes in meal times as being

objectively unhealthy, whereas the considerable variability in meal times around Europe (Southerton, Díaz-Méndez & Warde, 2012, particularly Figure 1) suggests this is likely to be a cultural construct and so can be considered alongside the social norms theme described below.

*Minding the neighbours: The social acceptability of time-shifting (mentioned by 39% of participants)*

An issue raised by 13 participants was noise as a barrier to time shifting. This was a particular problem for appliances such as lawn mowers, vacuum cleaners, washing machines and tumble dryers. All of these are, as noted above, in the key high-consumption high-discretion category that we particularly want to target, and so the issue is a concern. Participants with children (who sleep early) and neighbours were most concerned about re-scheduling the use of these appliances:

*Washing machine. Again see this is the tricky one because I live in a terrace so if I knew that it was going to cost me more during the day I wouldn't have any choice because the walls are paper thin. P11*

*Vacuum cleaning. I know it takes quite a lot of energy but I don't think we would do it during midnight or the morning because that would disturb neighbours and disturb [my] baby, so I think we would still use it at the same time. P09.*

Notably, participants were not raising these topics in the context of injunctive social norms (Schultz, Nolan, Cialdini, Goldstein & Griskevicius, 2007); they were not saying that washing clothes at night is socially unacceptable in the sense of being 'improper'. Rather, they were focused on a very specific social issue, which is that of not wishing to cause disturbance to neighbours or family members. Possible solutions could involve quieter appliances or segregated, isolated laundry areas (as found in the basements of some mainland European apartment blocks).

*Household Dynamics (mentioned by 24% of participants)*

For households with multiple members, shifting the time of energy use was perceived to be more challenging. In particular, there was an issue of *collectivity*: the energy consumption of a household is the sum of its various members' actions, meaning the use of appliances or the undertaking of certain household tasks was not necessarily within the volitional control (or responsibility) of the specific participants with whom we spoke. This in turn means that time-shifting is perhaps most likely for tasks 'owned' by one member of the household who has the autonomy to control that task or, for tasks without a clear owner, if all members of a household share some responsibility for the shifting – which might require people to hold explicit conversations about the subject:

*Again, this is during the day and this is when I am not in the house so I don't feel like I have any control over what happens at that time other than to say to [my husband] don't do washing during the day today. P25.*

*There will be a television on in the house [...] the TV could be on from seven until [my daughter] goes to school, so say nine. And then by the time my missus gets in it will go back on. It will probably stay on until she picks up the little one up from school at quarter past three. And then after that, once [the] little one gets back, the TV will be on until probably about eleven unless my son stays up all night watching TV. P17.*

#### *Norms and Social Comparison (mentioned by 15% of participants)*

Comparing themselves to others emerged as a potentially important reason for participants not shifting time of use (Gifford, 2011). Such responses appeared to be particularly given in response to the prototype tariff that showed only the carbon price of electricity. Participants particularly used social comparisons to construct their own consumption as requiring no engagement or change. This could be through describing their own consumption as *normal* compared to others:

*When I use it – that’s just normal [...]. That’s probably the difference between a single person and a family. [...] I’d say everything I use is essentially for myself. I don’t use a lot. P23.*

or, even more extreme, through describing their own consumption as *minimal* compared to others:

*I think I only use a minute amount compared to other people, I think I am quite meagre anyway as I don’t wish to pay. I have never wasted like [my daughter]. If you were to ask [my daughter] all the windows would be open letting all the heat out. She wouldn’t understand the question. P24.*

Presumably, people exhibiting this self-minimizing belief would be particularly difficult to reach for demand-side response. Given the weight participants seem to put on social comparison, and given that half of households are, by definition, above mean consumption, there could well be a role here for in-home displays that provide social comparison information (Chiang et al, 2014), albeit perhaps only to those who are currently consuming more than average, to avoid unintended increases in consumption. An advantage of smart in-home displays is that they can provide each householder with referents that are most meaningful. For example, like the participant quoted above, a person living alone can always downplay the need for behaviour change by constructing their usage as less than the national average household consumption – but they might change their behaviour more if shown how they compare to a referent like other one-occupant households.

#### *Welfare of others (mentioned by 9% of participants)*

Only a few participants made statements in this theme. This is notable given that parenting was what led Nicholls and Strenger (2015a) to be pessimistic about ToU tariffs, and reminds us that, whilst caring might be an important behavioural influence for those who have such roles, there will be plenty of people who do not have such roles, and the potential utility of ToU tariffs for these people is perhaps greater than suggested in that earlier study. Moreover, although we certainly saw statements aligned with Nicholls and Strenger’s findings (“I don’t think [my baby]

would accept changing the dinner times” – P09), there was still evidence of flexibility with respect to non-daily tasks (e.g., laundry). One parent, in fact, stated that she was motivated by the idea that shifting and curtailing energy use could be important for teaching her child about environmental issues:

*I would definitely postpone any Hoovering, washing machine, dishwashing [...]. I think it would be good for [my daughter] to [...] learn that this is something that is an issue. And to have these changing [i.e., the timing of tasks] would be a really nice way to show her and to prompt some questions and dialogue on that as well. P25.*

This finding is in line with research by Fell and Chiu (2014) who found evidence that parents showed a greater inclination to pay attention to energy conservation when this was framed in terms of supporting their child’s learning, than when the message was simply framed in terms of financial or environmental benefits. In the case of Participant 25, both environmental and parental motives can be seen in willingness to change energy behaviours. Taken together, these findings suggest there is potential for ToU tariffs and in-home displays not only to engage people with varying motivations but also to act as tools to facilitate intergenerational learning.

A key question raised by one participant from a household with children was how the information on carbon intensity would be communicated to her family:

*I think in order for that to actually apply to our household it would need to be flagged very obviously by the energy companies and if it went for example by email to the person who pays the bill it would go to [my husband] and I am not sure that that information would then automatically pass on to me. P25*

In future practice, it would likely be the job of an in-home display to communicate such information, which raises important questions about how such devices should be designed if they are usefully to influence behaviour (Chiang et al., 2013, 2014).

#### Strategies for responding to ToU tariffs

Finally, the transcripts revealed specific behavioural strategies described by participants as they thought about how they might minimise financial and/or carbon cost in light of the ToU tariffs. Here, briefly, we list these from the most to the least commonly described:

1. Bringing forward or postponing energy consumption (i.e., demand-side response)
2. Changing the appliance used for the task (e.g., switching from the cooker to the microwave)
3. Using certain appliances less overall, but not shifting the time of consumption (seen particularly for tasks like making hot drinks)
4. Monitoring: Giving changes to household routines a trial period to see whether they actually make changes to energy bills
5. Cooking meals in the oven at off-peak times and then heating them up in the microwave at peak times
6. Investing in more energy efficient appliances to reduce overall energy consumption

7. Shifting the location of electricity use (e.g., charging mobile phones at work and showering the gym)
8. Prioritising tasks so that only those considered “essential” take place at peak times
9. Automating: Using timers to facilitate time-shifting
10. Charging batteries at lower times to use appliances when energy prices increase (e.g., mobiles and laptops)
11. Being out of the house generally, to avoid electricity use at peak times

The finding that straightforward demand-side response – i.e., shifting the timing of consumption – was the dominant strategy is promising given the focus of this study. However, it was certainly not the only strategy people considered for avoiding costly consumption times and we also saw a range of substitution, curtailment and investment behaviours being mooted. Given that the topic of energy literacy might become increasingly important as we ask householders to take a more active role in energy production and use (Hope, Roberts & Walker, 2018), it is notable that strategy 5, while likely to keep bills down, would also increase overall energy consumption and, possibly, carbon emissions. Similarly, strategy 7 would probably not actually reduce demand at peak times or carbon emissions but merely shift the cost to another bill payer. It is also worth observing that strategy 4 might be enhanced with the provision of effective in-home displays (IHDs).

## DISCUSSION

This study used a think-aloud protocol to explore decision-making when people were shown putative time of use (ToU) tariffs representing variable financial and carbon costs of energy consumption. Participants were more receptive to a complex three-tier tariff than a simple two-tier tariff, going as far as considering demand-side response behaviour for the three-tier tariff that they specifically ruled out for the two-tier tariff. The two-tier model was perceived as overly simplistic and incompatible with the routines, roles and practices in people’s lives. The former, on the other hand, was received quite warmly, particularly by participants who were able to take advantage of the mid-afternoon price dip (which, at least at weekends, could be many people). This all suggests that tariffs intended to stimulate demand-side response (DSR) will need to show temporal variability, which maps to some extent onto people’s beliefs about their own routines, or else risk rejection. Li, Wang, Gu, Li and Wu (2016) showed that a three-tier tariff like the one tested here is ideal for domestic energy solutions incorporating battery storage, meaning there are now both engineering and behavioural pushes towards the adoption of such tariffs.

Participants also in some cases showed sensitivity to information about the carbon cost of future consumption, with the majority who saw this information seeking explicitly to strike a balance between financial and carbon cost. This suggests people might in some cases respond to predictions about the environmental cost of their consumption if this can be provided, particularly as a second-tier influence on behaviour. This could be a useful insight in the future for shaping DSR – particularly for ecological benefit – in people who are not sufficiently motivated by financial savings.

Participants showed a strong tendency to classify tasks into those performed daily and those performed less than daily. The data suggest that appropriate variable ToU tariffs could encourage

postponement of daily tasks such as cooking by an hour or more – which would be sufficient to offer network and environmental benefits. Harder to shift, however, might be behaviours repeated at daily or sub-daily frequency that are also perceived as short (showering<sup>1</sup>, making hot drinks), even though these can be relatively energy intensive. The barrier here seems to lie with the routine nature of these activities combined with the perception that, being short, their consumption must be low (a failure of energy literacy – van den Broek & Walker, 2019a). It might now be useful to look for ways of addressing these that do not rely on behaviour change but rather on technology (e.g., storing off-peak energy for on-peak use – Wang, Gu, Li, Bale & Sun, 2013).

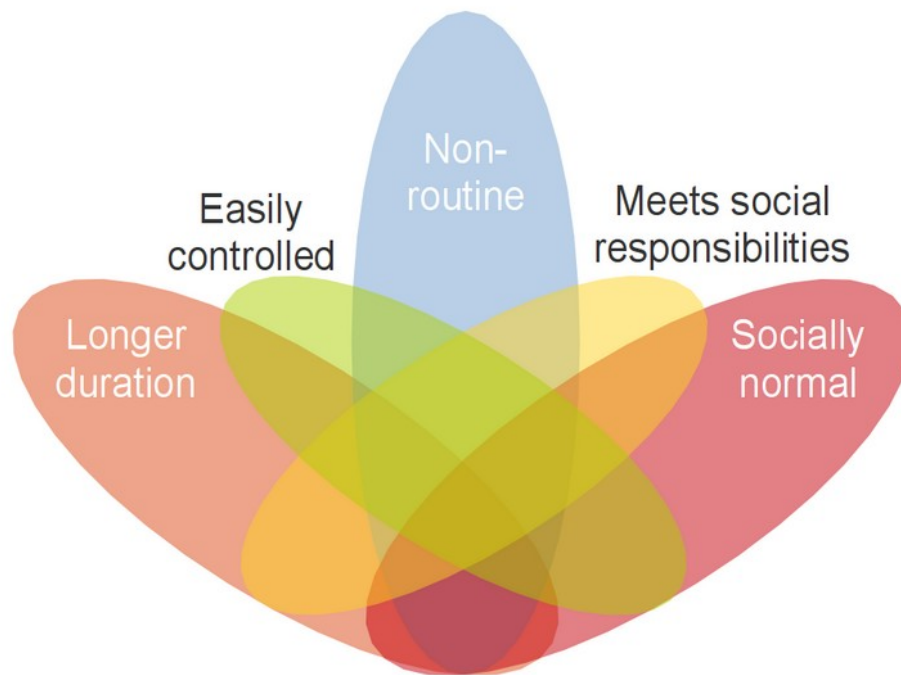
In Figure 1, we presented the a priori framework that we thought might describe people's perceptions of consumptive activities in relation to DSR. Our data certainly suggested that the temporal discretion axis has psychological reality to people. On the other hand, only two participants explicitly mentioned the energy demands of the activities, even though kiloWatt hour measures were written on each transparency (Figure 3). This suggests the energy consumption of activities is not very salient to people. Whilst many of the tasks identified by participants as non-daily (and hence high in discretion) were also those high in energy consumption (e.g., using clothes dryers, irons and vacuum cleaners), this focus on the top-right quadrant of Figure 1 probably arose because people focused on temporal discretion and most of the high-discretion activities we presented happened also to be high-consumption. Participants' lack of attention to energy demand when thinking about DSR supports the literature suggesting a general lack of energy literacy in the public (e.g., DeWaters & Powers, 2011; van den Broek & Walker, 2019a, 2019b; cf. Hope, Roberts & Walker, 2018). The neglect of consumption among participants in this study also hints that a useful role for in-home displays (or whatever other feedback interface is implemented) in the future might be to increase the salience of consumption information amongst the public, to help them better perform DSR by changing the most consumptive behaviours.

More generally, the data from this study suggest there might be important dimensions missing from Figure 1 altogether, including task duration, social acceptability, household dynamics, norms and social roles. Our updated framework for describing how people might make DSR decisions is presented in the form of a Venn diagram in Figure 4. This illustrates the suggestion, arising from the data presented here, that whether or not a behaviour is shifted in time in response to financial or ecological incentives will depend upon the degree to which a set of criteria are met. This model is conceptual and is not intended to cover every factor that might influence a person's consumption timing; moreover, some factors will likely be more important than others. But the overall claim of this model is that the more criteria that are met when a person is asked to change the timing of a behaviour, the more likely is demand-side response. The clear prediction would be that time-shifting is particularly likely for an occasional task, that is purely within the control (or, especially, the remit) of the decision-maker and that is being pushed towards a more socially acceptable time from a less socially acceptable time. Another, broader, implication arising from our account in Figure 4 is the reminder that energy consumption is a profoundly social act – a point often overlooked in engineering approaches to end-users.

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1 Recent data (Gallagher, 2018) show that showers are often far from short, but they are included here because they are subjectively *seen* as short by many people.





**Figure 4 – Conceptual model of demand-side response decision-making shown as a Venn diagram. Greater overlap between concepts represents a greater likelihood of demand-side response.**

The Results section lists specific behavioural strategies that participants appeared to consider for achieving DSR. Many of these would genuinely be useful at the population level and might be encouraged in the future – perhaps particularly automation. It is interesting that the strategies people discussed included both one-off investment behaviours (buying more efficient appliances) and short-term curtailment behaviours (reducing the use of appliances – Thøgersen & Ölander, 1995). This suggests that DSR might be better considered – both by householders and policy makers – at both short and long-term levels, and advice and incentives to householders targeted at both levels.

Overall, the data here present a relatively optimistic picture of ToU tariffs. This is in contrast to the main previous study on this subject by Nicholls and Strengers (2015a, 2015b). A possible reason for this is that our sample was more diverse, including adult-only households, single occupant households and participants with more flexible working hours. It seems Nicholls and Strengers’s focus on parenting might have led to their more pessimistic judgement about DSR, which in itself is interesting.

Less clear at the time is why trials like those in Faruqi and Sergici (2010) achieved only modest DSR of around 3-6%. Perhaps the most plausible explanation is that people in those trials experienced exactly the social and practical barriers identified here. A new trial that specifically addresses these barriers with live ToU tariffs would now be a valuable addition to the literature.

This study is a qualitative exploration, aimed at generating new insights rather than testing hypotheses; as such, there was no aim for the sample to be representative of the wider public.

We note that there was a spread of incomes across our sample, which we hope means we have not simply gathered the impressions of the more affluent householder for whom price signals might have little meaning. That said, our sample was relatively small and there is no guarantee that every householder's response to tariff and carbon signals is captured here. We have also not included every important behaviour: heating is a clear area that could be explored as an extension of this study. If energy suppliers or policy-makers seek to implement DSM, and take on board some of the insights presented here, there will likely be a need for more rigorous market research at that time.

## CONCLUSIONS

When presented with hypothetical energy tariffs that showed time-variable financial or carbon information, participants showed a willingness to respond to relatively complex variable price structures. Indeed, the three-tier price structure tested here was preferred over a two-tier tariff – to the extent of prompting people to consider the very same behaviour changes that they were less amenable to under the simpler tariff. Demand-side response to variable prices seemed most likely when price structures reflected the routines, roles and practices people perceive in their own lives, with the distinction between daily and non-daily tasks being the most important. Appropriately timed peak and shoulder prices look promising for nudging people's energy consumption forwards or backwards in time – perhaps by an hour or more.

Participants also showed some willingness to change behaviour to minimise its carbon cost. Although in this study carbon reduction was seen more as something to be balanced against cost reduction, there were certainly indications that information about the future carbon cost of energy might induce demand-side response, particularly for high-consumption non-daily tasks, and this might be useful for people not sufficiently motivated by financial saving.

A broad range of barriers and opportunities for time-shifting were identified, and we suggest that demand-side response will be most likely when several of these align (e.g., when a person feels empowered to change the time of behaviour *and* this fits their social roles). Finally, it was clear that demand-side response was not the only strategy spontaneously raised by participants when they considered variable tariffs, and a broad range of short-term curtailment and substitution solutions, as well as long-term investment solutions, were spontaneously considered by participants when they thought about how they might avoid peak-time consumption.

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