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Peak demand reduction – who is flexibility, when and how?

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Please state here corresponding number and letter (e.g. 1a): 2b

Abstract

The energy crisis experienced in the UK during the winter 2022/23 forced the network operator to offer rewards as part of their Demand Flexibility Service (DFS). For the first time in the history of the national grid, private customers could be paid for using less during peak demand events. The scheme was delivered via energy suppliers and was considered successful enough to be repeated in winter 2023/24. For reasons of commercial sensitivity little data has been made available about the distribution of responses within the population. We share detailed responses from a sample of 200 UK households, who attempted to avoid peak demand across four seasons. Alongside high-resolution electricity use data, we present results from socio-demographics and detailed activity diaries collected during response events and during 'normal' control days. They show the impact of load shifting on everyday practices and gives insights into conditions that might inhibit greater flexibility.Our results show that it is not the extent of the financial reward that determines the load responsiveness. Some activity patterns are unexpectedly flexible, including meal preparation. Despite the perceived technical potential to shift heating appliances, gas heated homes only showed modest shifts in gas demand during flexibility events.We present detailed findings and an outlook for the continuation of this research as part of the newly established UK Energy Demand Observatory and Laboratory (EDOL), an £8m national and longitudinal data resource for the zero-carbon demand transition.

1. INTRODUCTION

Demand side response has long been proposed in literature as a means to support the integration of renewables, avoid network reinforcement and achieve system wide savings from more efficient operation of assets. (Grunewald & Diakonova, 2018; Grünewald et al., 2014)
Espey & Espey (2004) estimate the short term elasticity of electricity demand to be -0.35. Such figures are widely used in models and simulations of demand response and electricity system models (Bradley et al., 2013; Roscoe & Ault, 2010). Numerous studies state significant short term responses to price based demand response trials (Schofield et al., 2014; Torriti & Yunusov, 2020). However, Zhu et al. (2018) conclude after extensive meta analysis of international reviews that residential electricity demand is almost inelastic in the short term.
In addition to price based incentives, Buckley (2020) and Andor & Fels (2018) review non-price signals and nudges as an alternative signal for change. Importantly, they point out that small and short-lived studies tend to report greater effect sizes than larger and longer lasting studies.
Demand Flexibility Services were trialled commercially for the first time by National Grid ESO in the UK during the winter 2022/23. Among the motivations for the trial were supply uncertainties resulting from high gas prices.
The Guaranteed Acceptance Price (GAP) is £3,000/MWh for most auctions. This translates to approximately ten times the price of using electricity, for *not* using it. Suppliers bidding to provide the service can choose to pass on part of the savings to their customers or motivate them in other ways to participate.
1.6 million households and businesses supported the service. The ESO judged the trial to be a success and expects to continue the service and run 12 'test events' between November 2023 and March 2024. (ESO, 2022)
The exact breakdown and contribution from different sectors, suppliers or households is not published and is in some cases commercially sensitive.
This paper therefore draws on a study that made comparable demand reduction requests and collected additional information about participating households and their activities during interventions and on control days.

2. METHODS

2.1 The Energy Demand Observatory and Laboratory (EDOL)

Energy Demand Observatory and Laboratory (EDOL, 2023) is a major UK energy data infrastructure investment, funded by the Engineering and Physical Sciences Research Council (EPSRC), led by University College London in partnership with the University of Oxford. The programme seeks to provide a longitudinal, disaggregated, consistent and flexible resource of UK residential energy data. Representative and reliable data are made available to scientists, industry and policymakers. EDOL will innovate new, cost-effective, smart data solutions for collecting energy data at scale.

EDOL's Observatory will include 2,000 representative UK households and builds on the 12,000 households for which the Smart Energy Research Lab (SERL) is making smart meter and survey data available for research. In addition, EDOL will implement contextual data, such as temperature readings and occupancy.
EDOL Laboratories provide an environment for interventions, targeted panels and additional instruments. Technology trials, retrofits or engagement strategies will be tested for their effectiveness with respect to the observatory, which acts as a control group.

2.2 EDOL Flexibility Lab

The flexibility is an EDOL subset smart metered homes, which periodically receive requests to reduce demand. To assess how different publics respond to such requests, electronic diaries need to be submitted for the intervention day and a control day. The reward for two complete diaries and at least 10% demand reduction is £10.

2.3 The sample

The EDOL Flexibility lab sample consists of 157 participants that were recruited with the help of a commercial partner. From a proprietary online research panel of 100,000 members participants are recruited to be demographically, geographically and attitudinally representative of Great Britain. To improve the representativeness of the sample for the GB population with a smart meter, quotas by gender, region and work status have been applied at the recruitment stage.

The panel is regularly subjected to online surveys, for which they get financially rewarded. For this survey the incentives is £2. The survey covers socio-demographic and energy-use relevant questions, including affordability of energy and ownership of a smart meter.
To grant access to their smart meter data, participants have to provide the 16 digit alphanumerical GUID number underneath their in-home-display, which came as part of their smart meter installation. The GUID is validated against their post-code and uniquely identifies their smart meter. If the GUID-post-code pair is valid, participants receive a follow-up email inviting them to take part in the study by agreeing to the terms and conditions to access and process their smart meter data (Hildebrand, 2022).

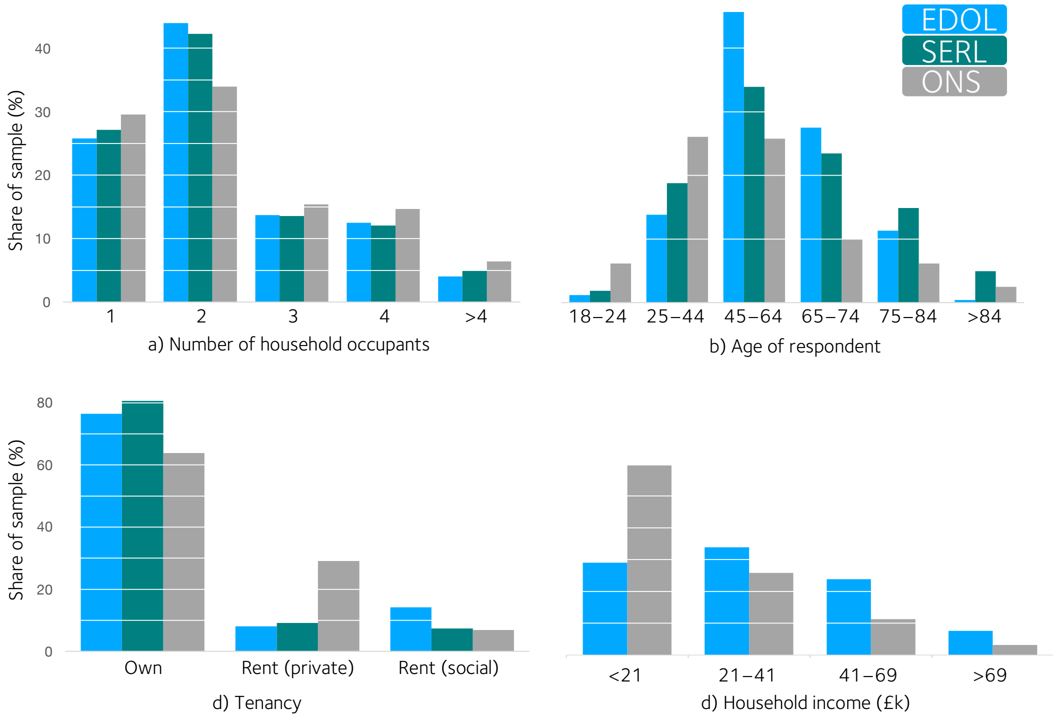

Figure 1: Sample distribution comparing the EDOL lab with SERL (Webborn, 2020) and national census data (National Statistics, 2022)

For participating in the study, installing a Consumer Access Device (CAD) and sharing their data for research purposes, participants receive a total annual reward of £15 in 2022, increasing to £20 in 2023. The survey is completed by 248 respondents. Of these, 200 have a valid smart meter ID and 157 provided consent and valid data.

Attempts to ensure representativeness of the sample do not entirely guard against selection and other biases. The smart meter population in Great Britain at the time of recruitment (January-February 2022) is just below 50%, with private rented properties slightly under-represented. The panel itself is likely to be self-selecting in favour of people who are more disposed to online engagement and monetary rewards. Some key characteristics of the sample are compared to the larger SERL sample and national statistics in Figure 1.

The sample has a good representation of household sizes, an over-representation of the 45 to 75 age group, and fewer households in privately rented accommodation. The tenancy bias is consistent with the SERL sample and stems from the complication of gaining landlord consent for smart meter access. The bias towards higher incomes is consistent with the over-representation of the middle-age distribution.

2.4 Trial conduct

All members of the Flexibility lab (n=157) receive an email one week before the control day. The email contains a personalised link to their activity diary and invites them to:

1. Record 20 activities each on the two consecutive days
2. On the second day between 5 p.m. and 7 p.m. they should attempt to reduce electricity use by at least 10%

The reward for successful completion of these tasks is £10. The Terms & Conditions are included in all correspondence. The email for any participant who reaches the required diary entries on the control day is shown in Appendix Figure 9. The dates for the four intervention trials is shown in Table 1. For the April 2022 trial the challenge was stated as 20% demand reduction. This was subsequently reduced to 10%.

All trials take place on adjacent Wednesdays and Thursdays, being two weekdays with similar load profiles under normal conditions. Mondays and Fridays follow different patterns and were therefore avoided.

Table 1: Trial and control day dates

Trial	Control date	Treatment date
April 2022	Wednesday 27th	Thursday 28th
June 2022	Wednesday 29th	Thursday 30th
October 2022	Wednesday 19th	Thursday 20th
January 2023	Wednesday 25th	Thursday 26th

After the treatment day participants receive personalised emails, depending on whether or not they reached the requirements. An example of the feedback provided to explain their results in the form of a graph is shown in Figure 2.
The first three trials were not within the core heating season. The request to reduce gas consumption as well was added to the December trial.

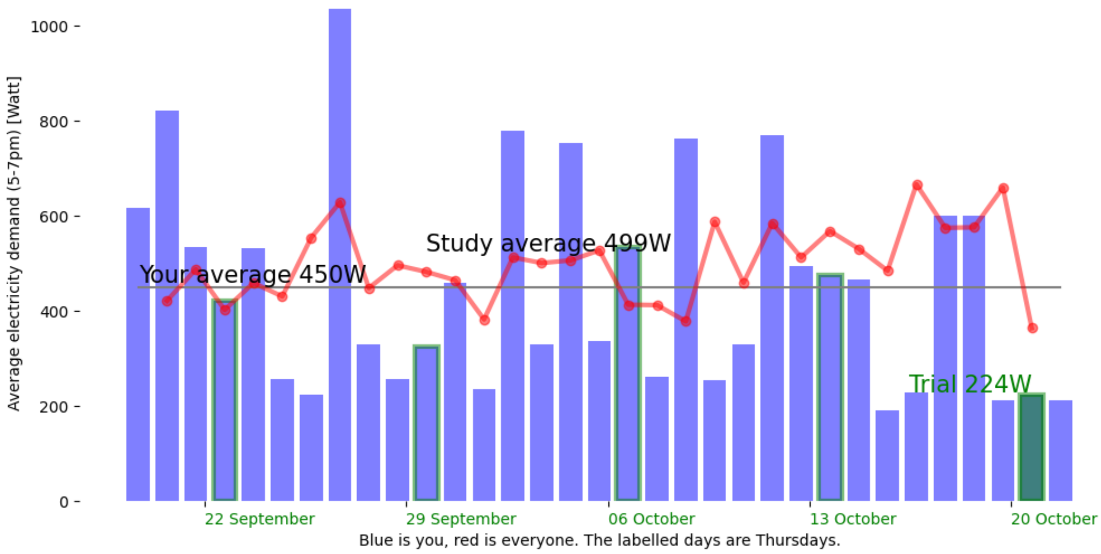

Figure 2: Example of the feedback sent to participants. Load reduction is assessed against the previous three Thursdays, labelled with dates and marked in green.

2.5 The data

Survey information is collected at the recruitment stage (see above) and in annual follow-up surveys, where participants receive an email inviting them to update appliance stock, household composition and attitudinal questions.

Smart meter data is obtained via two routes. Half-hourly data is transmitted from the smart meter via mobile signal and accessed through the Data Communications Company (DCC). One minute data is transmitted from the smart meter via the Home Area Network (HAN) to the Consumer Access Device (CAD) which is connected via Ethernet to the home router and transmitted via the internet to the Glow Service. The Glow Service makes both DCC and CAD data available via secure APIs. The data flow is illustrated in Figure 3.

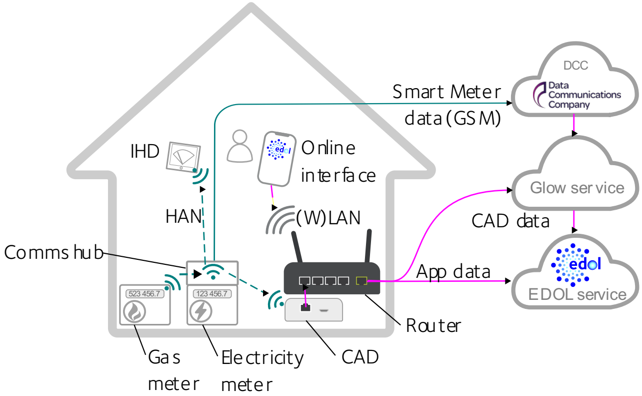

Figure 3: Data flow illustration. Smart Meter data is transmitted via GSM to the Data Communications Company, or via the internet to the GLOW service, which provides secure APIs for EDOL. User interfaces connect directly to EDOL services.

Smart meter data contains electricity and gas consumption and the cost of this energy at the time of use.

2.6 Activity diaries

The JoyMeter.uk (2023) interface allows participants to record everyday activities and appliances they use. This can be done on any mobile or desktop device. It is also possible to annotate one's load data directly. Recording the required number of activities on the control day is a pro-condition for participation. Only those who completed the diary day get the reminder email on the treatment day. The participation level is steady as shown in Figure 4.

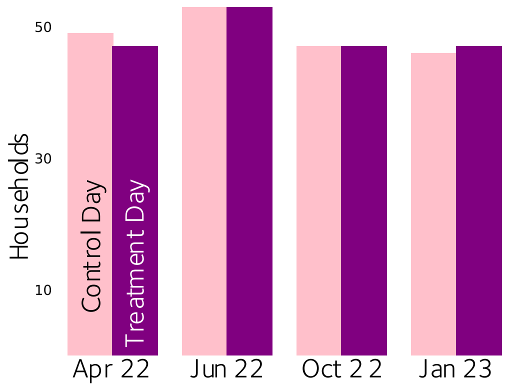

Figure 4: Participation rates are stable throughout the trial. Approximately a third of households take up and complete the challenge each time.

Energy, survey and activity data are linked via unique IDs and stored in a secure database. The data is anonymised and aggregated to protect the identity of participants.

Data collection is ongoing. At the time of writing electricity consumption and tariff data is available for 157 households. Gas data is also available, but the data quality is less suitable for time resolved analysis, because periods without readings are sometimes followed by a single half hour with the accumulated consumption of the missing periods. This can distort the temporal attribution performed as part of the elasticity analysis.

2.7 Analysis

Relative changes in electricity consumption (E^*) are derived as

$$E^* = \frac{E_t - E_c}{(E_t + E_c)/2} \quad (1)$$

where E_t and E_c are the electricity use on treatment and control day respectively. Using a differences-over-sums metric means that when plotting results, increases and reductions are distributed evenly around the zero point.

Participants are assessed individually based on the previous three Thursdays. This serves two purposes. Firstly it avoids gaming, whereby households may artificially increase demand in order to inflate their assessment baseline. Secondly, as apparent from the example in Figure 2, demand over a two-hour period can be volatile and a larger number of reference point makes the comparison fairer at the individual level.

For aggregate analysis, only the control day itself is used. This day is closest temporally and is the day for which comparable activity records are available.

3. RESULTS

The profiles of participants and non-participants exhibit similar peak time demand, suggesting that participants have not unduly attempted to game the challenge by increasing demand on the control day.

Comparing ‘opt-in’ participants with themselves, the peak demand reduction is 36.7% (relative change). When using non-participants on the same day as control, it is 31.6%.

The activity records suggest that most activity patterns remain unaffected by this intervention, as the example of one of the most commonly reported activity categories (‘screen time’) shows in Figure 6. A notable exception is “preparing hot meals”, which is reported noticeably fewer times during the treatment period (Figure 5).

Two thirds of participants successfully reduce demand by at least 10%, regardless of season. However, the average reduction is noticeably lower in January, as shown in Figure 7 and Table 2.

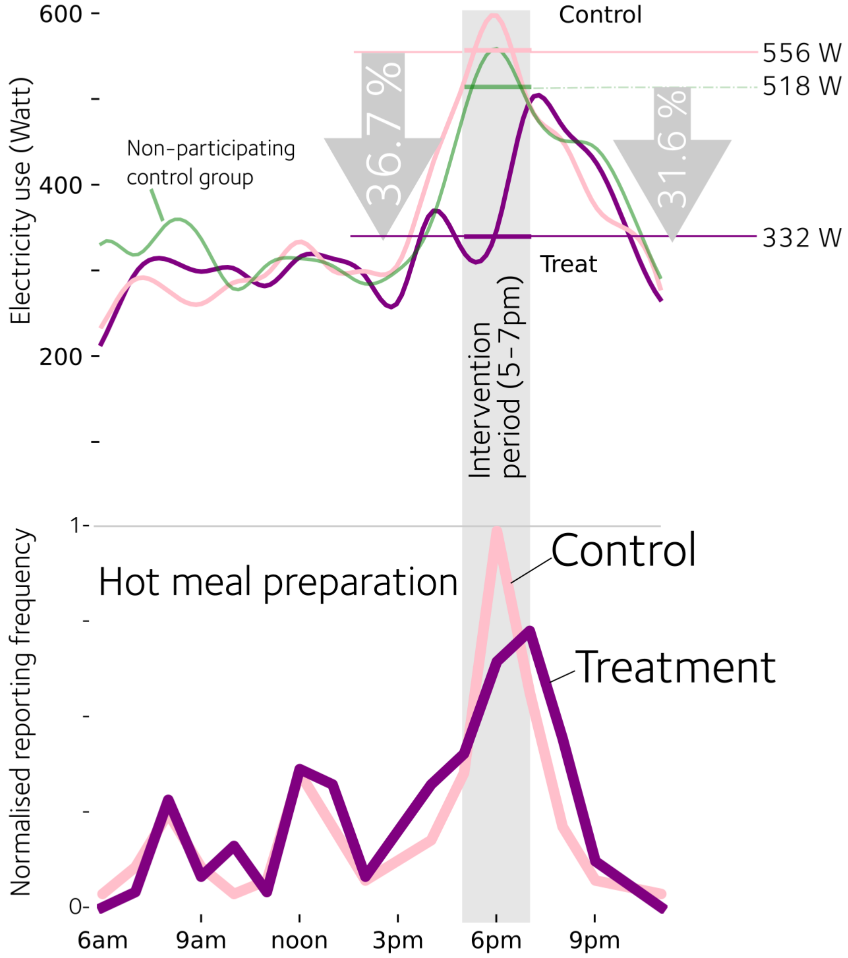

Figure 5: Load reduction with respect to the control day is 36.7% on average. Relative to non-participating households on the same day the reduction is 31.6%

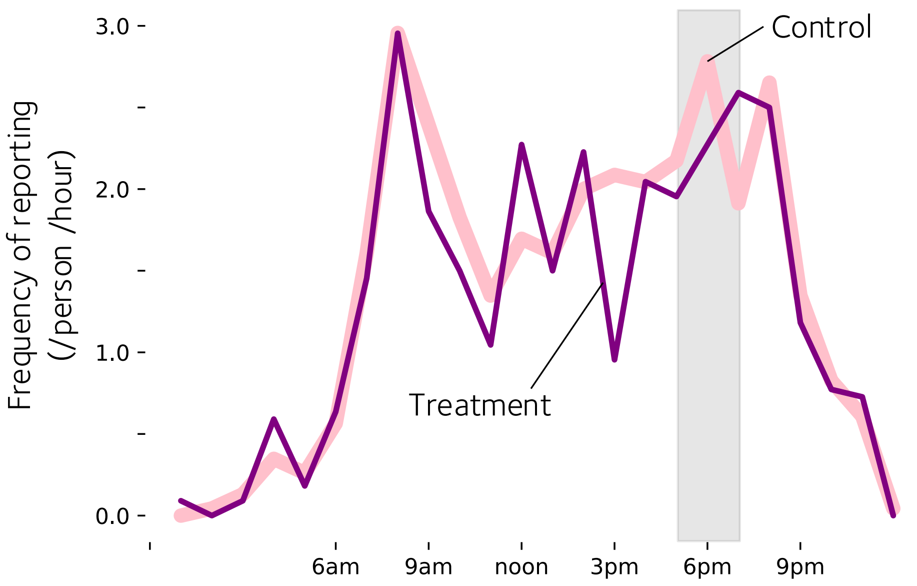

Figure 6: Screen time is among the most frequently reported activities and remains largely unchanged by the request to reduce demand.

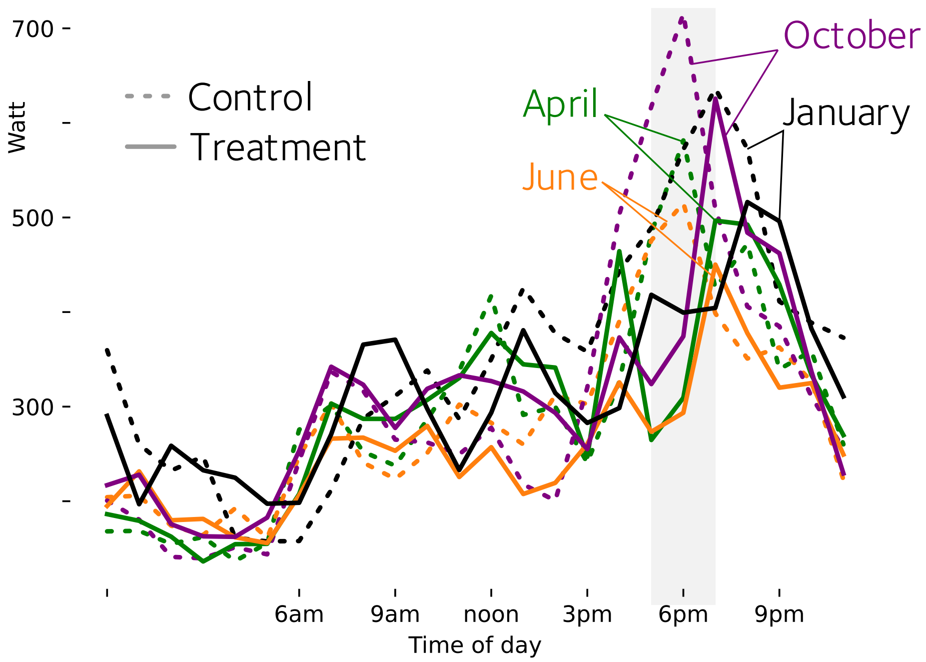

Figure 7: Participants achieved significant savings during the 5 p.m. to 7 p.m. window, regardless of season.

Whether participants are asked to reduce by 20%, as in trial 1, or merely 10% as in the subsequent trials, does not appear to make a material difference to the average reduction. Participants tend to reduce 'as best they can'. A larger number of trials would be required to verify this relationship, given the variability of responses.
Some participants reported that they failed to reach the 10%, despite their best efforts. The variability in demand over such short periods is high, as shown in Figure 2. It may therefore not always be under the participants control if they reach the target on a given day. Some aggregation may help to mitigate this risk.

Table 2: Electricity use between 5 p.m. and 7 p.m. on control and treatment day

Trial	Control (Watt)	Treatment (Watt)	Change (%)
April 2022	532	287	44.3
June 2022	495	283	39.9
October 2022	666	349	46.5
January 2023	530	409	18.0

Figure 8 confirms that households with lower demand on the control day are less likely to reduce demand. This is to be expected in both absolute and in relative terms. Households with a higher baseline have greater potential to shift or avoid demand.

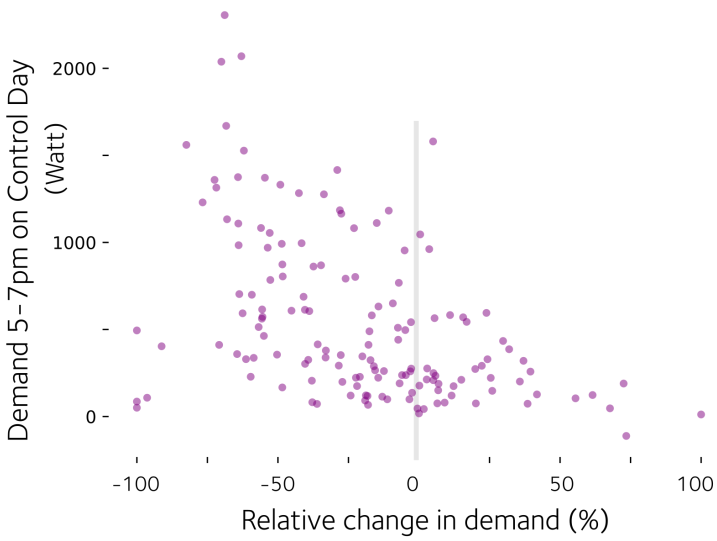

Figure 8: Participants with lower electricity demand between 5pm and 7pm on the control day achieve lower relative reductions during the trial.

4. DISCUSSION

GB households have demonstrated significant, repeated and reliable peak demand reduction potential.

Some participants were highly engaged and requested detailed feedback and advice. Among them were extremely low energy users who questioned what else they could do to reduce demand further during the trial, given that they already avoid energy use as much as possible. Participants who are in the bottom decile of electricity use were therefore given a compassionate exemption and received their reward regardless of load reduction (or in recognition of load reduction on a different scale). For policies and market arrangements, this raises equity questions over who 'deserves' rewards for peak demand reduction: those who reduce from a high base, or those who are low users all the time.

The ability to reduce load appears to be impacted when constraints on demand or attempts to reduce demand are already in place. Figure #results2 shows that lower users have less reduction potential. Furthermore, in January 2023, just after the energy price cap reached its record high of £4,279, households may have already been trying to reduce demand as evident from Figure 7. On this occasion the load response was lower than in the three trials the previous year.

Only on the January trial were participants asked to reduce gas consumption as well. The smaller sample makes analysis less reliable, but the data indicates that the load reduction was less successful than for electricity. This is surprising, given that heating is considered one of the more flexible loads. Participants may have had less agency over the timing of their heating system settings, but further work is required to verify how responses may be improved.

5. CONCLUSIONS

Dynamic load responses have proven to be an effective way to reduce load at critical times. Repeated trials across all four seasons have shown that load reductions are repeatable and reliable in aggregate.

A third of invited panellists participate in each trial, of which two thirds successful reduce demand at peak times by at least 10%. The average reduction across the sample is 36.7%, which is at the high end of responses reported in the literature. The monetary incentive is not the only motivation. Participants report enjoying the challenge and repeat their participation.

Many activity patterns do not appear to be adversely affected by the intervention. Hot meal preparation is among the most consistently shifted activities.

The ability to reduce demand depends on baseline demand patterns, with high users most able to act flexibly. The equity of reward schemes for flexible 'high demand households' over persistently low users requires policy attention while programmes are translated from trials into mainstream market instruments.

ACKNOWLEDGEMENTS

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APENDIX

Dear {name},

Well done for reaching {cnt} diary entries yesterday!

Please do the same again today and try to **reduce your energy use between 5pm and 7pm**. The aim is a 10% reduction in electricity use.

Tips for the day:

- For this challenge it doesn't matter how much energy you use before 5pm or after 7pm. If you can move activities or heating to earlier or later in the day, that's great
- Demand you can avoid altogether is even better
- Focus on the big items: heating, ovens, washing machines, dishwashers - they all use a lot.

Participation remains voluntary and this challenge is not meant to be a burden on you. If for any reason you find it difficult to complete, please get in touch.

Good luck today!

Phil

Dr Phil Grunewald, FICE
Energy Demand Observatory and Laboratory (EDOL)
University of Oxford

Terms and conditions

- The reward will be £10 BACS transfer or equivalent NewVista points based on your chosen payment method
- The 10% reduction is assessed against the past four weeks of electricity and gas data between 5pm and 7pm.
- 20 activities have to be recorded on each of the two days using your personalised link
- University of Oxford and NewVista staff are excluded from claiming this reward
- The University of Oxford reserve the right to withdraw the competition and alter the terms at any time without notice

Figure 9: Email sent on the morning of the trial day with instructions and terms and conditions.