PROJECT VENICE – IMPACT OF THE COST-OF-LIVING CRISIS ON DOMESTIC ENERGY CONSUMPTION

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This report was co-produced by Frontier Economics and University College London (Dr Ellen Zapata-Webborn and Dr Eoghan McKenna of UCL).

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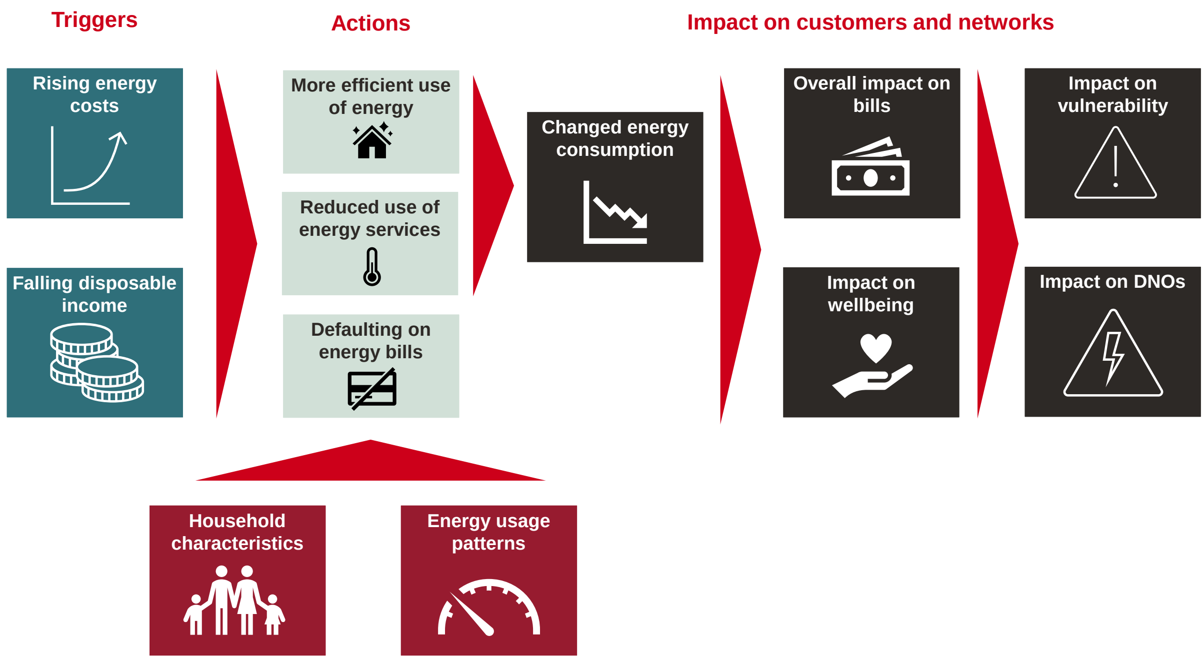
EXECUTIVE SUMMARY

Over the course of 2022 and into 2023, substantial rises in household expenditure have led to a cost-of-living crisis. One of the main contributors to this has been the significant increases in energy costs. Frontier Economics was commissioned by National Grid Electricity Distribution (NGED) as part of Project VENICE (Vulnerability and Energy Networks, Identification and Consumption Evaluation), funded through the Network Innovation Allowance (NIA) mechanism, to analyse the impact that this had on customer behaviour and its implications for electricity networks. The value of this study comes from being able to identify individual households over time and observe their consumption changes in response to the price shock, as well as identifying what actions they took to save energy during the cost-of-living crisis.

Approach

Figure 1 sets out the framework we have used to understand how the rising energy prices and cost-of-living crisis could lead to households taking action to reduce their energy expenditure and how this feeds through to both a personal impact and also an impact on the energy networks.

Figure 1 Illustration of impacts of the cost-of-living crisis on domestic energy consumption



Source: *Frontier Economics*

Using this framework we developed a set of questions to answer as part of this work:

- What has been the impact of the cost-of-living crisis on domestic energy consumption, considering both electricity and gas?
- What has been the subsequent impact on bills?
- How has the impact of the crisis been mitigated by actions taken by households?
- Has the impact been different across different groups of households, particularly those in vulnerable situations?
- What does this mean for the DNOs' role in serving peak demand and helping vulnerable customers?

To answer these questions we worked closely with researchers at University College London (UCL). With these researchers we were able to analyse historic household-level smart meter data from UCL's Smart Energy Research Lab (SERL) Observatory dataset dating back from Autumn 2021 up until 31st December 2022. This historic data enabled us to observe actual electricity and gas consumption for part of autumn/winter 2022 (i.e. October to December 2022) for just under 6,500 households. We were able to use a combination of data from the previous year (2021) and other information (e.g. on weather) to create predicted consumption for winter 2022, absent the cost-of-living crisis.

In addition to the consumption data, UCL led a follow-up survey of the SERL Observatory participants in January 2023 in partnership with Frontier Economics to identify specific behaviours in response to the cost of living crisis and relevant household demographics. The household information from this survey was matched with the household consumption data.

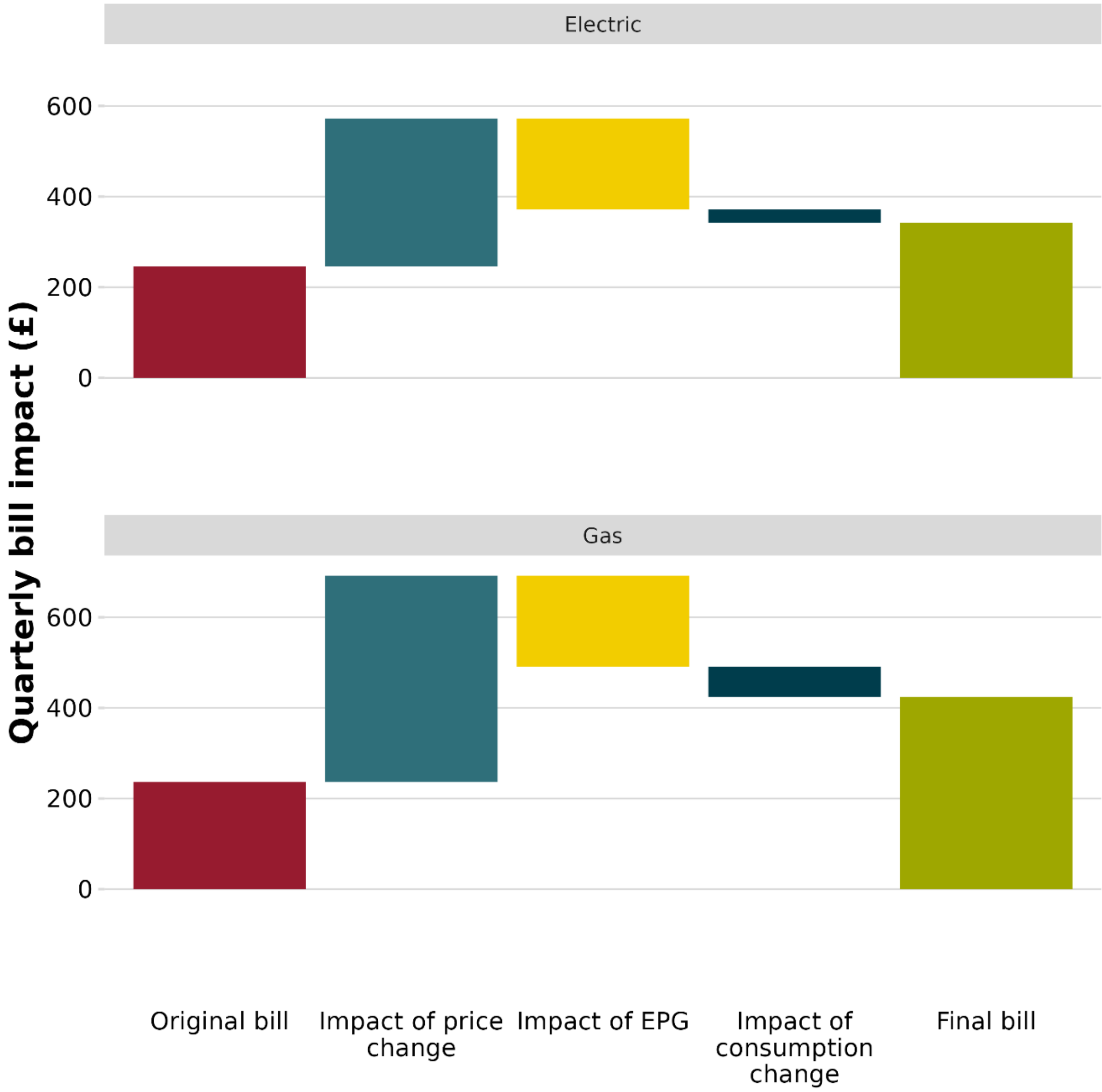
This meant we could observe, for each household, their predicted and actual energy consumption for October to December 2022 (thereby identifying the impact of the cost-of-living crisis) as well as identify characteristics and behaviours of that household. We could then group households that had similar characteristics together and observe outcomes for those household groups.

Before analysing the data, we reviewed the literature on the topic and identified some hypotheses we wanted to test in the data.

Results

We found that both electricity and gas consumption reduced by a substantial amount during the three months considered (October to December 2022) versus the predicted level of consumption. Gas consumption fell by 14% and electricity fell by 8%. While the impact was greater for gas, as we expected due to the use of gas for heating for the majority of properties, the change in electricity consumption was still substantial. This was slightly higher than reported in previous literature for electricity but similar for gas. However the fall in energy consumption did little to offset the rise in energy prices, see Figure 2.

Figure 2 Average change in normalised household bills across all households for October to December 2022



Source: Frontier Economics analysis of SERL data

Note: To get a normalised bill, we scale consumption relative to the Typical Domestic Consumption Value. The Energy Price Guarantee (EPG) is the guarantee that provides a support rate discount to all households with a domestic gas and/or electricity contract. This was introduced on 1 October 2022 and reduced bills below the price cap level.

We found the following:

- Total household bills increased by £225 on average across the three months considered (£75 for electricity bills and £150 for gas bills), taking into account price increases (that increased bills) and subsequent changes in consumption (that decreased bills).

- We were able to estimate how much households were able to save on energy bills as a result of changes in consumption in electricity and gas. In total this was around £96, which was made up of £29 for changes in gas consumption and £67 for changes in electricity consumption.
- The resulting overall change in bills meant that levels of fuel poverty increased from approximately 12.5% of our sample to 15.7% of our sample.[1] [2] [3]

There was variation in how energy consumption changed across the period considered. Changes in consumption (as a percentage of overall consumption) were largest in October for both gas and electricity. By December, consumption had reverted closer to expected consumption. This coincided with very cold temperatures in December. This is illustrated by Figure 3.

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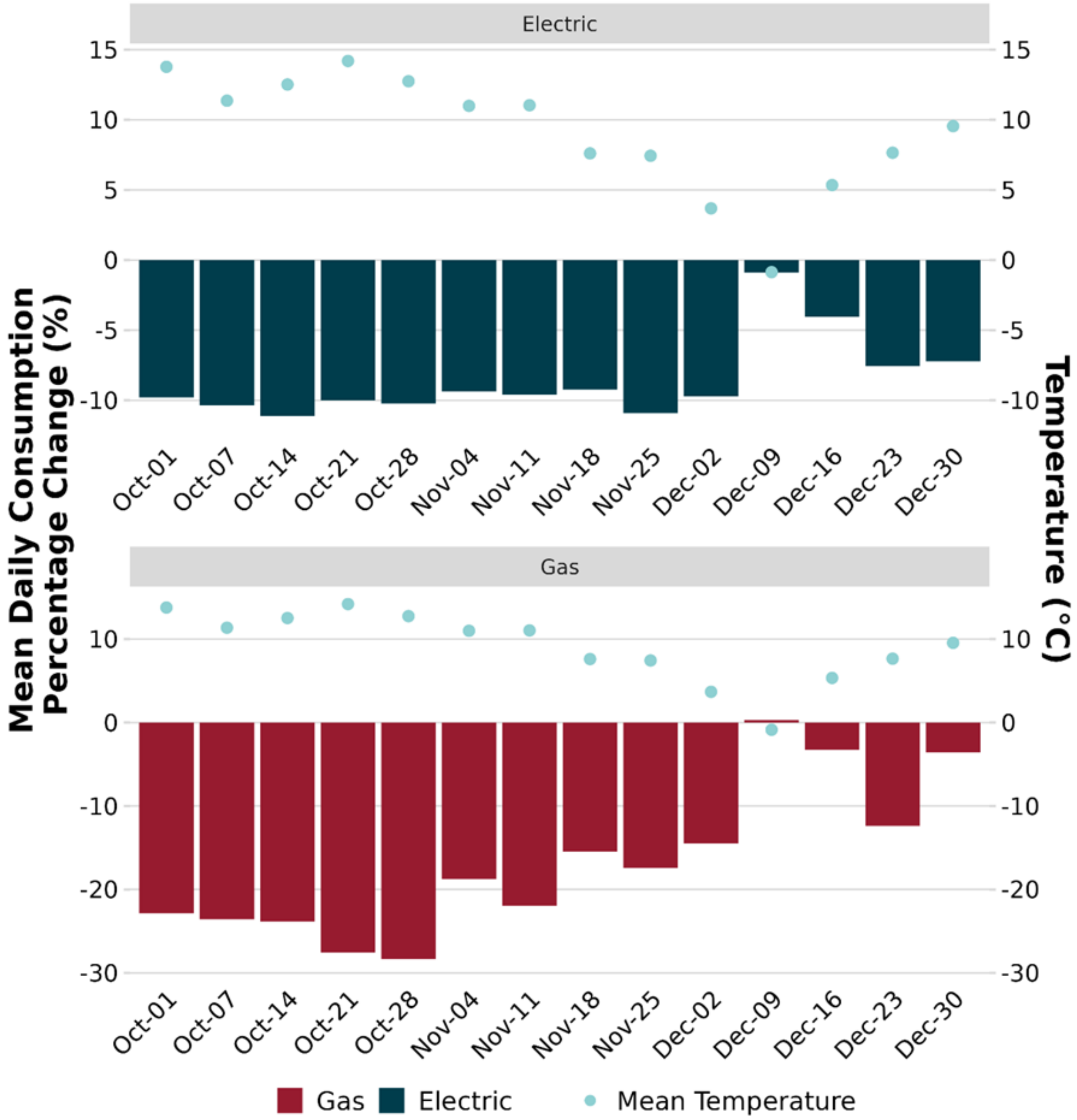
1 Based on an estimated calculation of fuel poverty using the UK Government definition, as seen in Annual Fuel Poverty Statistics in England, 2023

2 The definition of fuel poverty in England is defined as households with Low Income and Low Energy Efficiency (LILEE). These households have an EPC rating of D or below; and, after heating their home, they are left with residual disposable income below the poverty line (after tax and housing costs). Annual Fuel Poverty Statistics in England, 2023

3 We only adjust household prices for the Energy Price Guarantee in our analysis. We do not take into account of extra payments for those on benefits received as a result of the crisis. This is because many of these benefits are means-tested and we are not able to identify the households who are eligible.

Figure 3 Changes in consumption and temperature by week for October to December 2022



Source: Frontier Economics analysis of SERL data

We found the following:

- In October, when the weather was milder, the change in consumption was large.
- As the weeks got colder on average through the year, gas consumption began to revert back towards predicted consumption.
- In week commencing 9th December, when the weather was coldest, gas and electricity consumption reverted back to almost exactly predicted consumption.
- When temperatures began to warm, behaviour did not entirely revert back. This may suggest that households were not taking energy saving actions to the same extent. It is

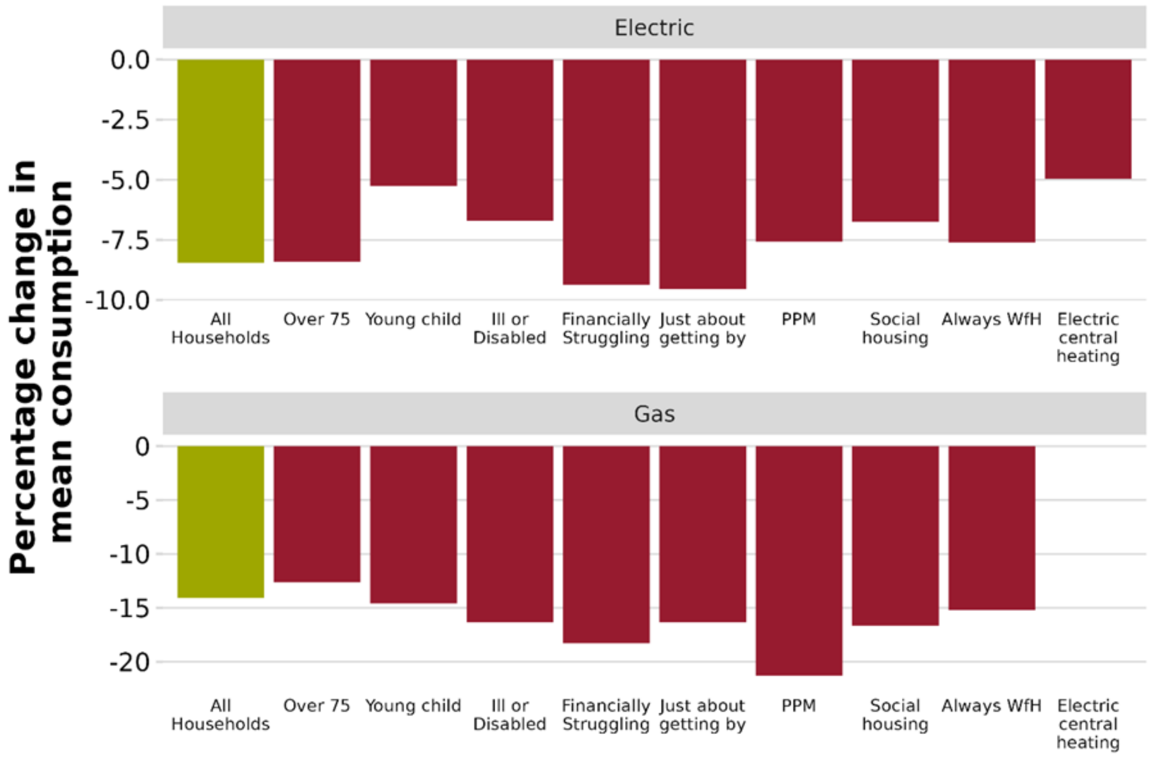
difficult to draw firm conclusions given that the period also coincides with the Christmas and New Year period where behaviour may be impacted for other reasons.

- However since our data ends at the year end, we have not been able to investigate whether the lower-level response rates persist even when the temperature increases.

These aggregate changes mask the fact that some households did a lot to change their consumption and some did very little. Around a quarter of households were reducing gas consumption by more than 45% in October, but a similar proportion reduced gas consumption by less than 10% in the same month. For electricity around a quarter of households reduced consumption by more than 20% while there are also a similar proportion of households who did not change their behaviour, consuming around the levels that would have been predicted.

We also considered how the impact varied between different household groups. We considered a set of households that might be considered vulnerable as well as households of particular interest to NGED (such as those in social housing and households with changing working patterns as a result of the pandemic). Figure 4 summarises each household group's change in consumption.

Figure 4 Electricity and gas consumption change across household groups



Source: Frontier Economics analysis of SERL data

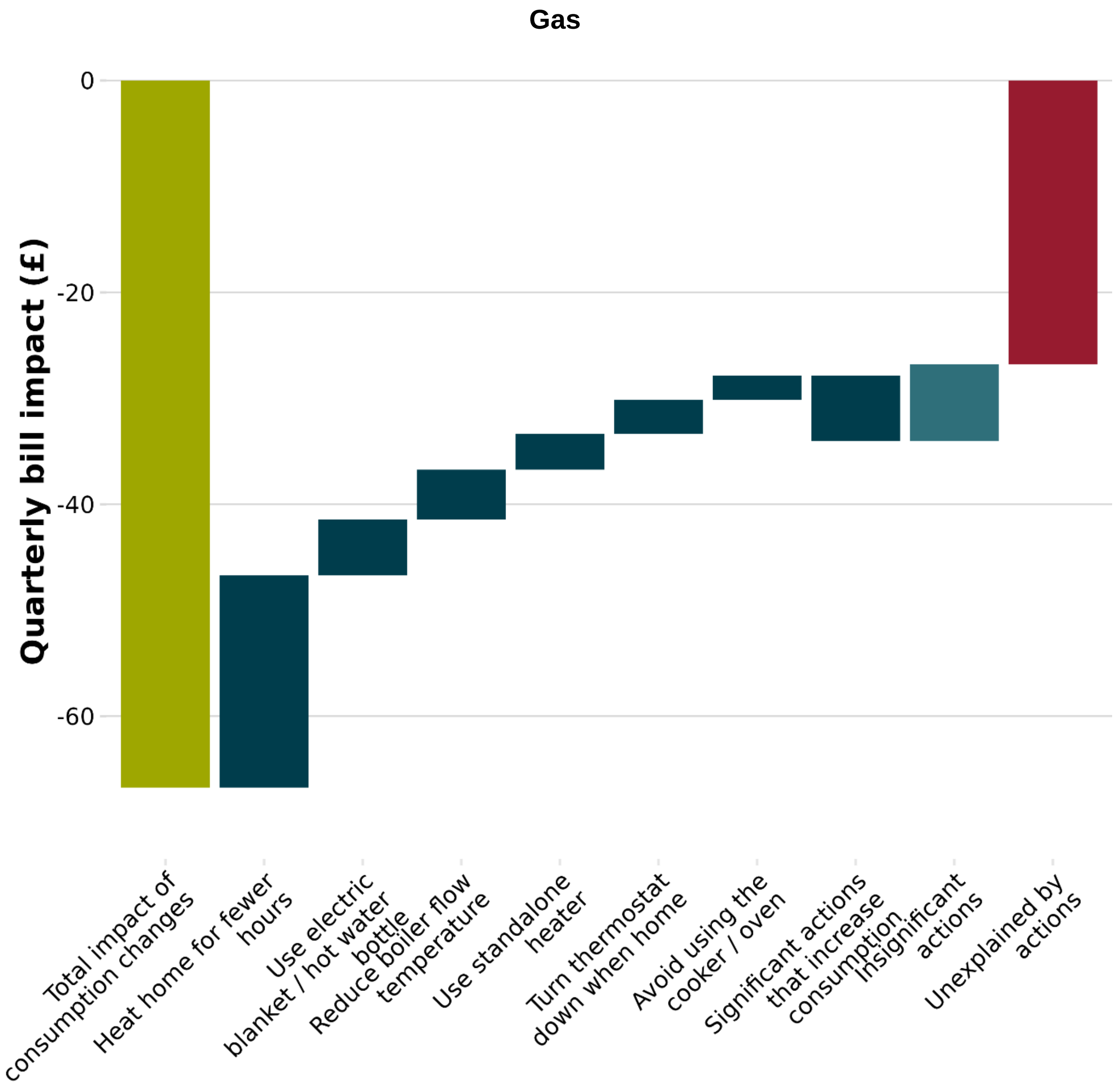
Note: Scales differ between the electricity and gas charts. PPM stands for pre-payment meter customers

We found that:

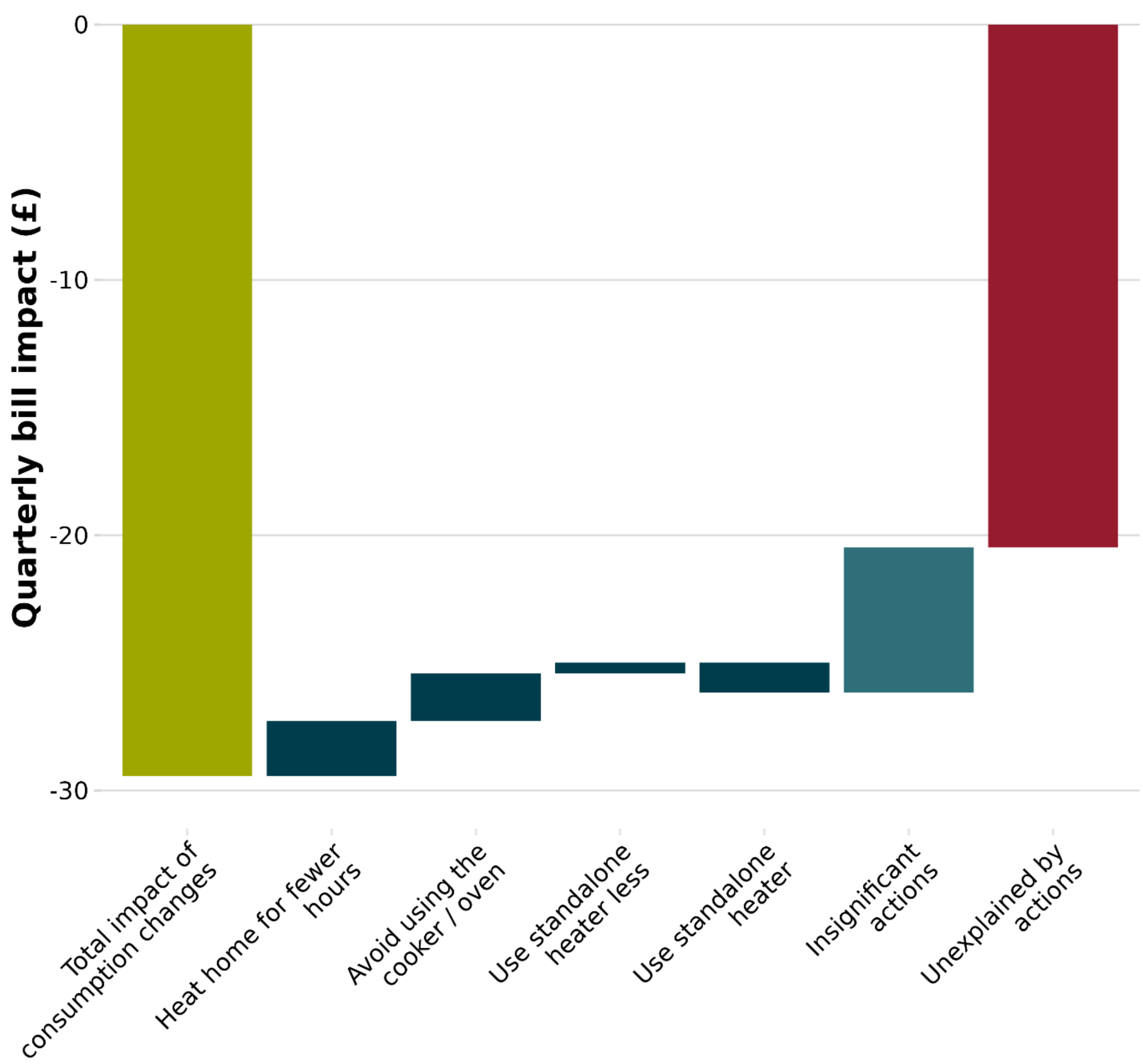
- Households that reported that they were 'financially struggling', 'just about getting by' or on pre-payment meters reduced consumption more than other households. This reflected their increased propensity to take almost all energy saving actions more than other households. This is a troubling finding: households who are 'financially struggling' may already have been underheating their homes while those households with prepayment meters may be engaging in harmful self-disconnection or rationing.
- Households with elderly people tended to change gas consumption less than other households suggesting their priority was to maintain heating their home.
- While almost all household groups saw an increase in the number of households in fuel poverty, households with elderly people saw the biggest increase as over 35% more households fell into fuel poverty. This reflects the fact that households with elderly people made smaller reductions in consumption than average.
- At least a quarter of households that are 'financially struggling' and those that are ill and disabled reduced gas consumption by more than 30%. Both these groups include customers in vulnerable situations who are reducing gas consumption by a substantial amount. The result of this is likely to be significant under-heating of homes.

Using the survey that we commissioned we were able to ask households about what actions they took to reduce energy consumption over the winter and whether these actions were additional to actions taken in the previous winter. Using regression analysis, we can estimate the relationship between taking different kinds of actions and changes in energy consumption. We can use this to illustrate the extent to which actions reduced consumption. Figure 5 shows the impact of each action on overall changes in consumption. The bill impacts shown here depend on both the effectiveness of each action, as well as the overall proportion of households who undertook it.

Figure 5 The impact of changes in gas and electricity consumption on bills by actions



Electricity



Source: Frontier Economics analysis of SERL data

Note: The red bar ('Unexplained by actions') refers to a number of possible things that may impact energy consumption changes from year to year. For example, this could refer to changes in household composition, inaccurately reported actions, increasing energy efficiency actions not captured in this regression.

Using this analysis we found that actions to reduce heating demand generally had the most impact on bills, with heating the home for fewer hours saving customers on average £20 on their gas bill, and £2 on their electric bill in the 3-month period. This is because this action:

- was one of the most common actions, undertaken by over 50% of households; and
- had the largest impact on bills for households who undertook it (£33 over the three-month period for a typical consumer).

There is also good evidence that those that chose to take compensatory measures to heat themselves rather than their home were able to reduce their energy consumption further and save additional money. Indeed, using a hot water bottle or an electric blanket provided the second highest saving associated with all actions (at £16.32 for the 3-month period). There is also evidence that those that used standalone heaters managed to save enough money on their gas bills to compensate for the increase in electricity costs through use of the heaters. If households can fully mitigate discomfort through compensatory actions, then this is an effective way of reducing energy bills.

A third of households reduced heating consumption but did not compensate for this in other ways. The extent to which this is concerning depends on whether households were previously overheating their homes.

Implications for NGED and other DNOs

The implications of this analysis for NGED and other DNOs are twofold. First, there are implications for network planning, specifically on demand forecasting and for estimating access to flexibility. Second, there are DNO obligations associated with identifying and supporting customers in vulnerable situations.

With respect to network planning:

- When considering short term forecasts of demand on the network, DNOs will want to consider the context in which consumption has changed this winter. We are unable to observe whether reductions in consumption remained over the course of the winter and therefore we don't know whether the reductions we see between October and December 2022 will mask underlying trends that increase peak demand in future. However the level of domestic energy consumption will continue to depend on ongoing energy prices and broader economic conditions moving forward so it is important to keep this under review.
- Over the upcoming winter, this will require ongoing monitoring from DNOs to understand how consumption changes. This should be considered in the context of conservative forecasting of peak demand, given DNOs may prefer to overestimate the level of peak demand than underestimate it. In the long run, DNOs will need to understand how heat pump behaviour compares to behaviour in gas boilers. We consider that there might be fewer actions that heat pump households can take, which makes reductions in consumption much smaller in particularly cold periods. At the moment NGED's DFES does not consider how behaviours might change over time but note that smart meter data should be used to monitor this behaviour change and "incorporated into the profiles".[4]
- More generally it is clear that households will change their heating behaviour in response to price signals, often at a cost to their own comfort. We find that this is true, to some extent, for households with heat pumps. However, given we find that households with heat pumps have fewer ways of varying their heating consumption, DNOs might want to gather more evidence into how customers can use heat pumps more flexibly and what incentives they require. NGED have started this work with project EQUINOX.[5]

4 Distribution Future Energy Scenarios, customer behaviour profiles and assumptions report, heat pumps, page 77, National Grid Electricity Distribution, 2022

5 EQUINOX (Equitable Novel Flexibility Exchange), NGED, https://www.nationalgrid.co.uk/projects/equinox-equitable-novel-flexibility-exchange

- It is also important to understand where households are inadvertently using more electricity than expected. For example, some households appear to be reducing gas consumption by increasing use of standalone electric heaters, but we also find using standalone electric heaters was associated with increased electricity consumption. While this was good for consumers, because the overall impact on bills was lower, it might be worth investigating whether this behaviour could impact the network during peak demand periods.

With respect to households in vulnerable situations:

- Our analysis finds that households with elderly people and households who identify as '*Just About Getting By'* are more likely to have fallen into fuel poverty as a result of the cost-of-living crisis. NGED may want to consider these households as increasingly vulnerable and focus its outreach activities on the groups that are more likely to contain fuel poor households. This might involve working with more referral partners who are specific to those groups.
- NGED can also use this analysis to provide energy saving advice to customers, some of which might be counterintuitive. The action that has most impact without heating the home for fewer hours is reducing boiler flow temperature. It is worth considering the organisations within NGED's existing network that would be best placed to deliver these messages, and providing them with evidence (including the analysis from this report) which can be used to justify the effectiveness of these measures.
- Educating households on the impact of different actions will be most important. Looking ahead, NGED will want to consider what the most effective energy saving advice it can give to households with heat pumps. This is because households with heat pumps had less scope to incrementally reduce heating consumption compared with households with gas boilers.
- Providing balanced advice through trusted partners will be critical in order to ensure households save money and do not underheat their homes. The non-financial impact on households from underheating their homes can be severe, so there is significant value in ensuring households remain warm.

1 Introduction

Frontier Economics has been commissioned by NGED as part of Project VENICE to analyse the impact of the cost-of-living crisis and increased energy prices on customers. Project VENICE is a customer oriented project commissioned by NGED and funded through the NIA funding mechanism.

This report serves as an extension to a project which was commissioned to consider the impact of the COVID-19 pandemic on domestic customers and electricity networks.[6] That report used customer-level smart meter data to consider the behaviours that changed during the pandemic, how these affected electricity consumption and whether they are likely to continue to affect electricity consumption in the future. This extension uses similar techniques to examine the impact of the cost-of-living crisis on energy consumption. We have worked closely with researchers at University College London (UCL), who led the necessary university research ethics and data access approvals, conducted the analysis to model what consumption may have been in the absence of the crisis, and led the follow-up survey used to identify energy savings actions taken by households. [7] [8]

We are using individual-level smart meter data accessed with household consent by UCL for the Smart Energy Research Lab (SERL) research project and made securely available to the UK research community via the SERL Observatory dataset. SERL undertakes research with smart meter data and provides a secure, consistent and trusted channel for accredited researchers working on approved research projects to access this unique energy data resource. This data includes household-level half-hourly electricity and gas consumption data that is linked to detailed information about the household and building gathered via Energy Performance Certificate data and a self-completion questionnaire. The SERL dataset already includes individual-level variables for household composition which we used in the VENICE report on the impact of the pandemic on consumption.

SERL recruited households to its Observatory in waves, with the first wave occurring in August 2018. There are now more than 13,000 households recruited for the SERL Observatory. In terms of the sample of homes, the SERL Observatory is recruited from a stratified (by Index of Multiple Deprivation and region) random sample of all GB addresses with a smart meter at the time of recruitment.

Unlike the previous work, we have considered the impact on gas consumption as well as electricity usage. This is because the majority of actions we expect households to have

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6 Frontier Economics, Zapata-Webborn, E., McKenna, E. (2023) Project VENICE: The impact of the pandemic on electricity consumption.

7 See acknowledgements section.

8 A more detailed description of the methodology applied by UCL for the previous work can be found in: Zapata-Webborn, E., McKenna, E. J., Pullinger, M., Cheshire, C., Masters, H., Whittaker, A., Few, J., Elam, S., Oreszczyn, T. (2023, March 21). The impact of COVID-19 on household energy consumption in England and Wales from April 2020 – March 2022. https://doi.org/10.31219/osf.io/m5p3b

undertaken in response to the cost-of-living crisis relate to heating, which for most households in the sample will be from gas boilers. The impact upon gas consumption is still relevant to NGED since:

- NGED has a broad duty towards customers in vulnerable situations and increased heating usage may have led to greater levels of vulnerability; and
- in future, a greater proportion of heating will be electrically powered. The way in which households change their heating behaviours in response to cost pressures will therefore be increasingly important for DNOs.

NGED is interested in answering the following questions:

- What has been the impact of the cost-of-living crisis on domestic energy consumption, considering both electricity and gas?[9]
- What has been the subsequent impact on bills?
- How has the impact of the crisis been mitigated by actions taken by households?
- Has the impact been different across different groups of households? Particularly those in vulnerable situations.
- What (if anything) does this mean for the DNO's role in serving peak demand and helping vulnerable customers?

To answer these questions, we have structured this report in four sections:

- **Section 2 – hypotheses for consumption change**. The first section generates a set of hypotheses, based on a review of the literature and available information, which can be tested in the data analysis. We set out what types of customers could change their consumption behaviour and consider what kind of actions different customers might be more predisposed to.
- **Section 3 – overall impact of the cost-of-living crisis on household consumption in GB**. This section describes, on aggregate, the change in domestic electricity and gas consumption over winter 2022/23 which can be attributed to the cost-of-living crisis. We illustrate the impact of this change on bills and break down the cause of the change into the impact of the different actions (such as turning down the heating) which customers undertook.
- **Section 4 – the impact of the cost-of-living crisis by household group**. This section breaks down the aggregate impact by household group, with a focus on customers in vulnerable circumstances. We identify whether the impact of the crisis (and the response of customers) differs between these groups.
- **Section 5 – implications for NGED and DNOs**. This section describes how the analysis is relevant to NGED and other DNOs. This includes analysing how DNOs might identify

9 We consider electricity and gas consumption separately since there are likely different drivers of consumption.

and support customers in vulnerable situations and what the results mean for future network planning and access to flexibility.

These sections are supported by four Annexes, which give a detailed review of the existing literature, details of the modelling methodology, a review of the sample representativeness and detailed analysis of household group consumption and action changes.

2 Hypotheses for consumption changes resulting from the cost-of-living crisis

This section sets out our process for generating the hypotheses for how customers will change energy consumption which we then test in the remainder of this report. To generate these hypotheses, we:

- give a brief overview of the cost-of-living crisis and how it is likely to affect NGED's customers;
- set out the framework for analysing changes in energy consumption as a result of the cost-of-living crisis and how those changes impact customers and energy networks;
- review the relevant literature on what actions customers might take in response to the cost-of-living crisis, how different customer types might respond, as well as the expected impact of these actions on consumption; and
- summarise our hypotheses, both overall and by household type, on how customers will change energy consumption.

At the end of this section, we summarise the key findings of this process and how the hypotheses we have developed feed into our analysis.

2.1 Overview of the cost-of-living crisis

Over the course of 2022 and into 2023, substantial rises in household expenditure have led to a cost-of-living crisis. Energy has been a significant part of this: as shown in Figure 6 below, in the period since Ofgem's price cap was introduced, annual bills (covering gas and electricity) for a typical consumer remained between £996 and £1,319. However, rises in wholesale energy prices led to customer bills sharply rising and by early 2023 the annual cap level was over £4,000.[10] Even with the Government's Energy Price Guarantee (EPG), typical bills were more than double the pre-crisis level at £2,500 for winter 2022/23.[11] [12]

Some additional support was also made available for different household groups. This included the £400 Energy Bills Support Scheme (which was applied to all households with an electricity connection); the means-tested cost of living payment of £650 available to those on certain benefits; and various benefits targeting pensioners, those on low incomes and people who receive specific disability benefits.[13] However, even after these payments, annual bills for

[10] Ofgem, *Default Tariff Cap*.

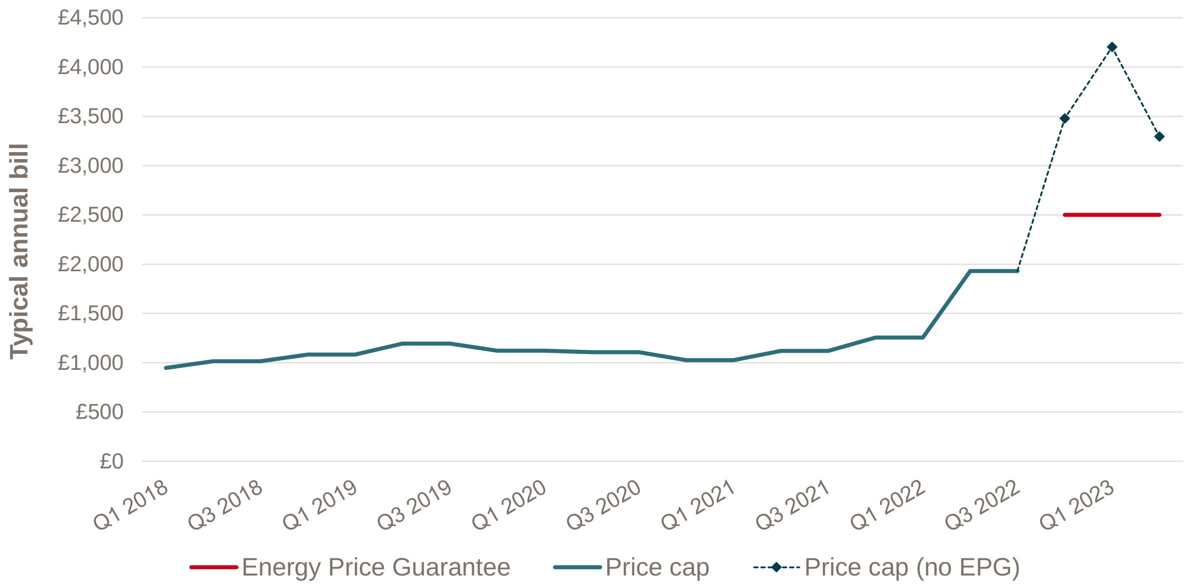
[11] Department for Business, Energy and Industrial Strategy. 15 March 2023. *Energy Price Guarantee.*

[12] Note that the Energy Price Guarantee was not a cap on total bills, but a cap on the unit cost such that a customer with 'typical consumption' (as defined by Ofgem) would pay £2,500 over the year.

[13] UK Government. *Help with your energy bills*.

a typical household would be around £1,500, above any historical levels. Since these payments did not affect the unit cost of electricity, households receiving this money still faced a strong incentive to cut back on use.

Figure 6 Energy bill for a typical customer on the default tariff cap



Source: Ofgem price cap model; Cornwall Insights (forecast data only); HM Treasury.

Note: Figures for a consumer using 12MWh of gas and 3.1MWh of electricity per year, paying by direct debit. From July 2023, households will pay the lower of the Ofgem Price Cap or the Energy Price Guarantee.

At the same time, household finances came under pressure from a number of other sources. These include the following.

- **Other energy costs.** High domestic gas and electricity prices have been coupled with increases to other energy costs, including motor fuels. Motor fuel inflation accelerated through 2022, peaking at 44% in July 2022.[14] The rate of increase has fallen since then and was 8% year-on-year in January 2023.[15]
- **Rising interest rates**. The Bank of England Bank Rate (BoE Rate) has risen from 0.25% in January 2022 to 5% as of 10th July 2023.[16] This has a significant impact on the outgoings of households with variable rate mortgages. The Institute for Fiscal Studies estimated that typical mortgage rates rose from approximately 2% in 2021/22 to 5.8% by February 2023.[17] This would on average reduce incomes after mortgage payments by

[14] Over the 12 months prior to July 2022

[15] Office for National Statistics. 24 March 2023. *Cost of living insights: Transport.*

[16] Bank of England. *Interest rates and Bank Rate.*

[17] Assuming mortgage rates rise at the same pace as the BoE Rate

7.5% across households with mortgages coming to the end of a fixed-rate deal during 2023 (estimated at 1.4million households).[18]

- **Broader inflation on other goods.** Energy prices are an input to many other goods and services. The high annual inflation rate for gas and electricity (129% and 67% respectively, as of January 2023) has contributed towards sharp price rises in other goods and services.[19] These other goods and services also face additional inflationary pressures. This includes food and non-alcoholic drinks, where prices have risen on average by 17% over the year to January 2023.[20] This puts further pressure on household finances and disproportionately affects low-income households who spend a greater proportion of their income on energy, food and non-alcoholic drinks than richer households.[21]

The combination of lower disposable income and higher energy prices has squeezed household finances and is likely to have caused many more households to fall into fuel poverty. These can be seen from data collected by SERL on household's' self-assessment of financial wellbeing (whether they consider themselves to be 'financially struggling'). Figure 7 indicates the SERL sample's self-reported financial wellbeing from when households first joined the sample (Autumn 2019) against when households answered the latest survey (January 2023) which we commissioned as part of this report (see Section 4 for more details).

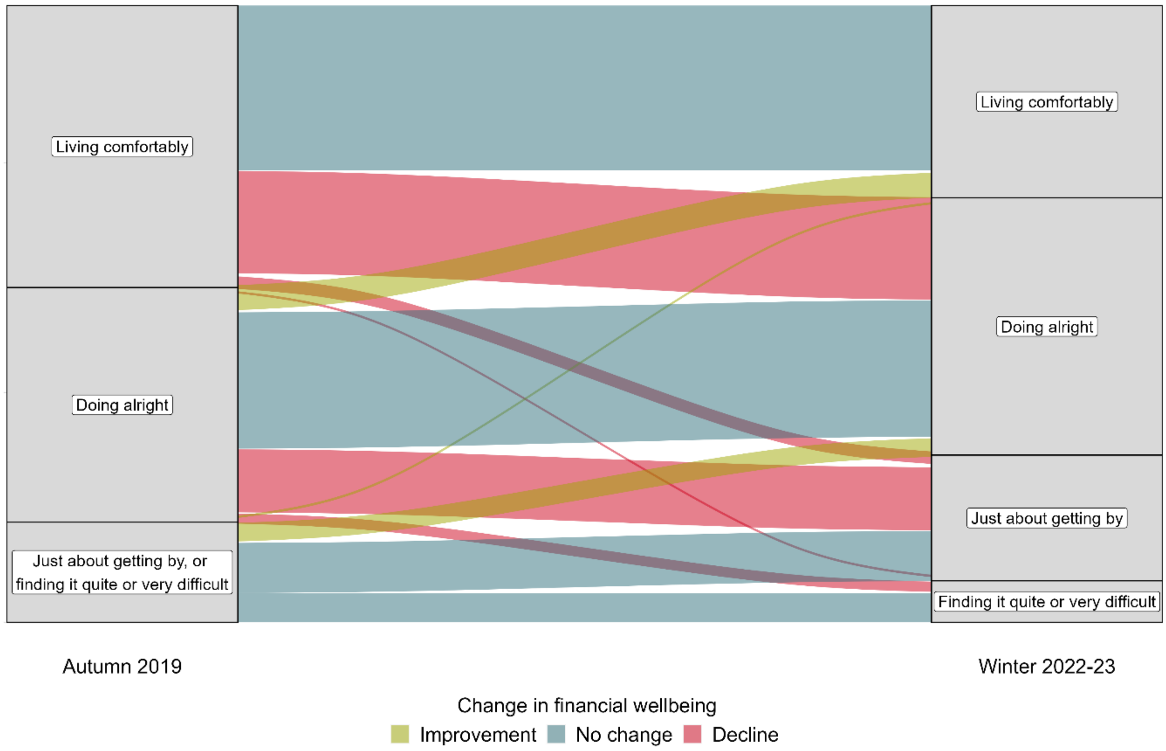
18 Institute for Fiscal Studies. 22 February 2023. *The cost-of-living crisis: a pre-Budget briefing.*

19 Office for National Statistics. 30 March 2023. *Cost of living insights: Energy.*

20 Office for National Statistics. 30 March 2023. *Cost of living insights: Food.*

21 Institute for Fiscal Studies. 22 February 2023. *The cost-of-living crisis: a pre-Budget briefing.*

Figure 7 Proportion of customers with different levels of self-reported financial wellbeing



Source: Frontier Economics analysis of SERL data

Between 2019 and 2022 there are more households with worsening financial wellbeing than households whose finances are getting better. There are large moves from those reporting ‘living comfortably’ to ‘doing alright’ and from those ‘doing alright’ to ‘just about getting by’. A large part of that will be due to the cost-of-living crisis.

Households may respond to this by seeking to reduce their energy consumption for two reasons.

- The first is the ‘*income effect*’: this describes the change in consumption of a good when the total income of a consumer decreases (i.e. the customer’s ‘purchasing power’). In this example, the price rises (both for energy and other goods and services) lead to lower disposable incomes. Customers may seek to offset this by reducing energy bills. Spending on other goods and services may also be reduced for this reason.
- The second is the ‘*substitution effect*’: this describes the effect when the price of a good changes relative to other goods and there is a subsequent change in consumption in other goods. In this example, if the price of domestic energy consumption rises faster than other goods and services, then every unit of energy consumed comes at a higher cost in terms of other consumption foregone. Customers therefore face an incentive to reduce their energy consumption so they can purchase other goods instead.

Efforts to consume less energy could take a variety of forms, including improving household energy efficiency (e.g. simple draughtproofing measures), reducing the use of energy services (e.g. heating fewer rooms) and customers who persisted with working from home post-pandemic returning to their workplace more often to reduce energy consumption. These types of responses are discussed in more detail in Section 2.2.

These effects are likely to be most visible in the winter period when energy consumption, particularly for heating, is at its highest. Therefore, we would expect the actions that households take in response to rising energy costs would be most prominent in the winter period.[22]

These issues are relevant to NGED and other DNOs, given their responsibility for customers in vulnerable circumstances, as well as their responsibility to understand what may happen to demand in response to price shocks. The datasets and analysis used for project VENICE are well suited to exploring them, since they allow us to examine the energy consumption of individual households over time, seeing how changes this winter may be associated with individual circumstances (such as financial distress).

2.2 Framework for analysing changes in consumption

We first need to understand the levers through which the cost-of-living crisis might impact energy consumption and customer vulnerability. Here, we identify and define each element of our framework, which is illustrated in Figure 8 below.

- **Triggers for change**: As described in Section 2.1, energy prices and other costs have risen over the course of 2022 and, for some costs, 2023. These increases may have driven changes in energy use through a variety of channels, through the income and substation effects described in Section 2.1.[23]

- **Actions in response**: Households may undertake a variety of actions, which can broadly be divided into:

  - **Energy efficiency measures,** which lead to less energy being used to produce the same output (e.g. heat or lighting). This might require home improvements, such as investment (e.g. installing draughtproofing), or smaller actions (e.g. reducing boiler flow temperatures).

[22] The winter period in GB is typically defined as the period from the day of clock change from British Summer Time (BST) to Greenwich Mean Time (GMT) in October to the day of the clock change from GMT to BST in March the following year. Source: Elexon. *Profiling: Seasons and day types.*

[23] Another trigger for change could be Russia's invasion of Ukraine. There may be some people who are motivated to reduce energy consumption in order to reduce reliance on Russian gas. However it is not clear how pervasive this behaviour is likely to be, particularly among customers in vulnerable situations, therefore we do not consider this as part of the framework.

- **Reductions in the use of energy services,** which lead to less outputs being produced. For example, choosing to heat fewer rooms, or not using the cooker. Unlike energy efficiency measures, these may be associated with consumer harms such as reduced access to hot meals, or worse comfort and health associated with under-heating.[24] In addition, customers who had continued to work from home following the COVID-19 pandemic might also choose to return to the office to save on heating bills – the extent to which this behaviour has a cost will depend on individual circumstances.[25]

- **Defaulting on energy bills.** This is when there are missed payments on energy bills after which the supplier could impose a prepayment meter on customers or disconnect them.[26] Please note that an analysis of bill defaults falls outside the scope of this work, although the analysis of PPM customers' consumption hints at the possibility that some customers are 'self-disconnecting' by allowing their credit to run out.

- The actions carried out by households may depend on their **household characteristics** (e.g. income) as well as **energy usage patterns** (e.g. houses that were never heated during weekday daytimes cannot further reduce during the same period).

- **Impact on customers and networks**: There will be a number of effects associated with customers taking actions in response to price rises:
  - The actions described above may lead to a **change in energy consumption**.
  - This will have an **impact on customer bills**. This effect will reduce customer bills below what they would have been had these actions not been taken (although bills may well still be higher than historically).
  - At the same time, reductions in the use of energy services could have **adverse effects on overall health and wellbeing**.
  - These impacts may then affect the number and types of vulnerability in a DNO's area.

As noted in Section 2.1, households may also respond by cutting down on non-energy expenditure (for example, reducing discretionary spend to prioritise bills) or even increasing it (if the 'substitution effect' is significant). The project does not quantify this expenditure, as our focus is on impacts on customers due to changes in energy consumption, rather than the broader effects of the cost-of-living crisis.

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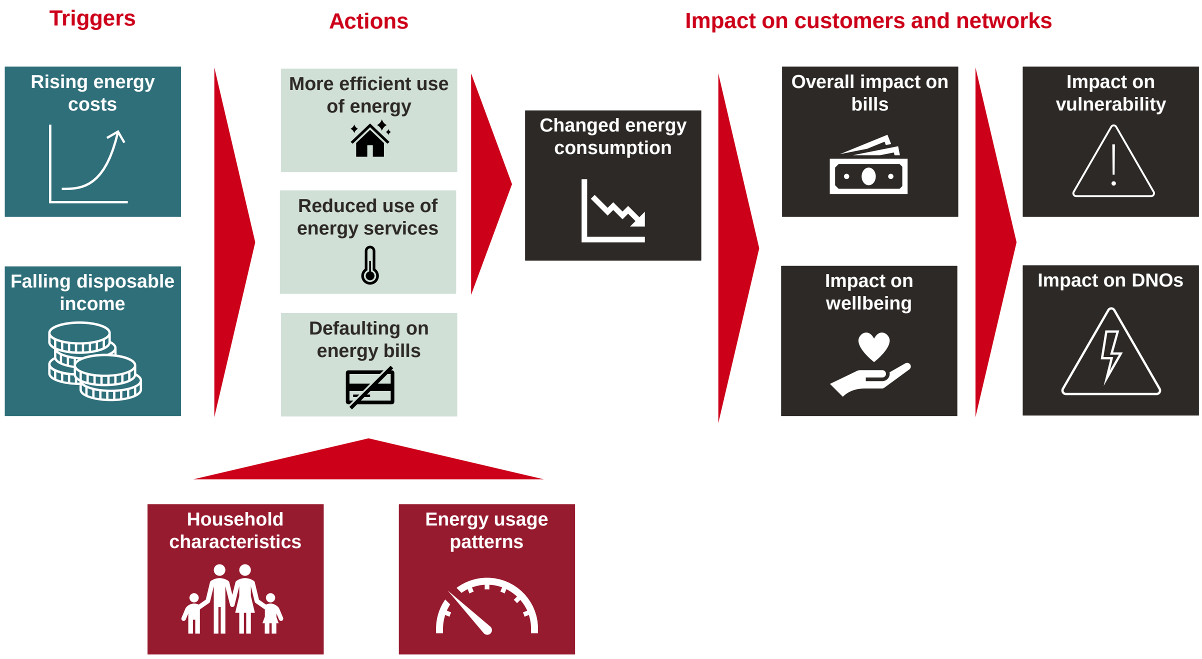
24 There may be some customers currently in over-heated homes; reducing consumption for these customers may not have impacts on wellbeing or health.

25 This behaviour may have wider benefits associated with returning to workplaces.

26 New restrictions have been placed on suppliers which means they cannot impose a prepayment meter on certain customers (e.g. over 85s) and have to meet specific conditions before installing.

Figure 8 Illustration of impacts of the cost-of-living crisis on domestic energy consumption



Source: Frontier Economics

2.3 Existing literature on the impact of the cost-of-living crisis on energy consumption

In this section we consider the questions set out in Section 1 and examine the previous literature that might help us answer these questions. We structure this section to focus on what existing research can tell us about those questions in order to form some hypotheses in Section 2.4. We consider the relationship between energy consumption and prices, before considering the extent to which households are taking actions in response to the crisis. We then discuss the potential impact of these actions. More detail can be found in Annex A .

At the time of writing, the literature that explores the current cost-of-living crisis is still relatively sparse, with no sophisticated analysis available that unpicks the relationship between the uptake of energy-saving actions and changes in consumption. However, there is some survey data, qualitative analysis and older analysis that discusses the general relationship between actions and consumption. The following sub-sections summarise our findings from the literature.

2.3.1 Relationship between energy consumption and prices

There is limited recent evidence around the relationship between energy consumption and prices, particularly in the UK where energy prices had previously been relatively stable for a number of years. Some estimates suggest that for every 10% that price increases, gas consumed declines by 1%.[27] Other estimates of electricity consumption showed a 13% reduction in response to sharp price rises.

While this illustrates that customers may respond to higher energy prices by reducing consumption, we would also like to understand what actions households can take to reduce consumption. For the winter period 2022-23, the advice can be summarised by Ofgem's four groups of bill saving tips. These are 'set and forget' actions, 'everyday small actions, 'basic home improvements' and 'larger home improvements'.[28] UK government's help for households also categorises in a similar way.[29]

There is some information around the actions reportedly taken in response to the cost-of-living crisis. We considered reports from the following organisations:

- YouGov showed that actions to reduce heating consumption are more prominent than actions to reduce electricity consumption. It also showed that the proportion of people taking actions is similar from October to December. It found that almost 75% of households are taking actions to reduce energy consumption of some sort.[30]
- Energy Systems Catapult found that households are using 40% less gas compared to the previous winter and homes are over half a degree Celsius colder. However, this was a relatively small sample size (85 households) and does not adjust for temperature.[31]
- International Energy Agency found consistent home heating behaviour with the ESC, with reductions in home temperatures on average around 0.6°C. Fuel poverty meant many vulnerable consumers reduced consumption because they could not afford the higher bills, leading to cold homes or a shift to cheaper and sometimes more polluting fuels such as wood pellets, charcoal, waste or low-quality fuel oil. However, this analysis was not-UK specific and covered Europe.[32]

2.3.2 Actions taken in response to the crisis by household group

Household groups considered

While the previous section looked at the relationship between price and consumption across all customers, we are also interested in how the impact of price changes may have varied

[27] In 2016 the Department of Energy and Climate Change (DECC) published an annex to a report on the available evidence on the impact of gas prices on domestic consumption in the UK. Department of Energy & Climate Change. June 2016. Gas price elasticities: the impact of gas prices on domestic consumption – a discussion of available evidence: Annex D.

[28] Ofgem, 2023. *Actions for saving energy*.

[29] UK Government. 2023. *Help for Households, Energy saving tips to save money.*

[30] YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

[31] Energy Systems Catapult. *Measuring the Consumer Response to the Energy Crisis in the Living Lab.*

[32] International Energy Agency.14 March 2023. *Europe's energy crisis: What factors drove the record fall in natural gas demand in 2022?*.

between different customer groups. Based on the questions of interest for this study (set out in Section 1) we focus on the following customer groups:

- Different socio-economic groups and particularly the customers in socio-economic groups Ofgem considers to be most vulnerable. We focus on customers that are eligible for the Priority Services Register (PSR). Within this set of customers, we focus on those groups which, given previous evidence, are more likely to be particularly vulnerable to longer-term reduction in energy use. The most prominent and relevant groups are:
  - The elderly, since they are more likely to reduce consumption;[33]
  - Households with children under 5, since they are more likely to feel cost of living pressures but least likely to change behaviour;[34]
  - Households with ill and disabled customers, although the evidence for this is more limited. Scope (a charity which provides support to people living with disabilities) found that 43% of disabled adults reported needing to use more energy to meet their needs and that 23% of disabled people were unable to heat their home compared to 10% of non-disabled people.
- We also consider households that are ‘financially struggling’ or in fuel poverty. Fuel poverty is defined by government as customers with poor energy efficiency in their homes and low incomes.[35] These customers appear to be more likely to take actions to reduce consumption than other households.[36] We also consider the buildings households live in since some houses (typically owner occupied and privately rented homes) are more likely to be energy efficient than other buildings (typically social housing).[37]
- Finally, we also analyse customers with persistent behaviour change as a result of the COVID-19 pandemic. These are typically customers that started working from home during the pandemic and maintained that working pattern afterwards. The Office for National Statistics reports that these customers are typically spending more money on bills.

Actions taken by households

We can also consider the different types of actions being taken by households. Research by YouGov, illustrated in Figure 9, considers different types of actions taken across the winter.

33 ONS Winter Survey; YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

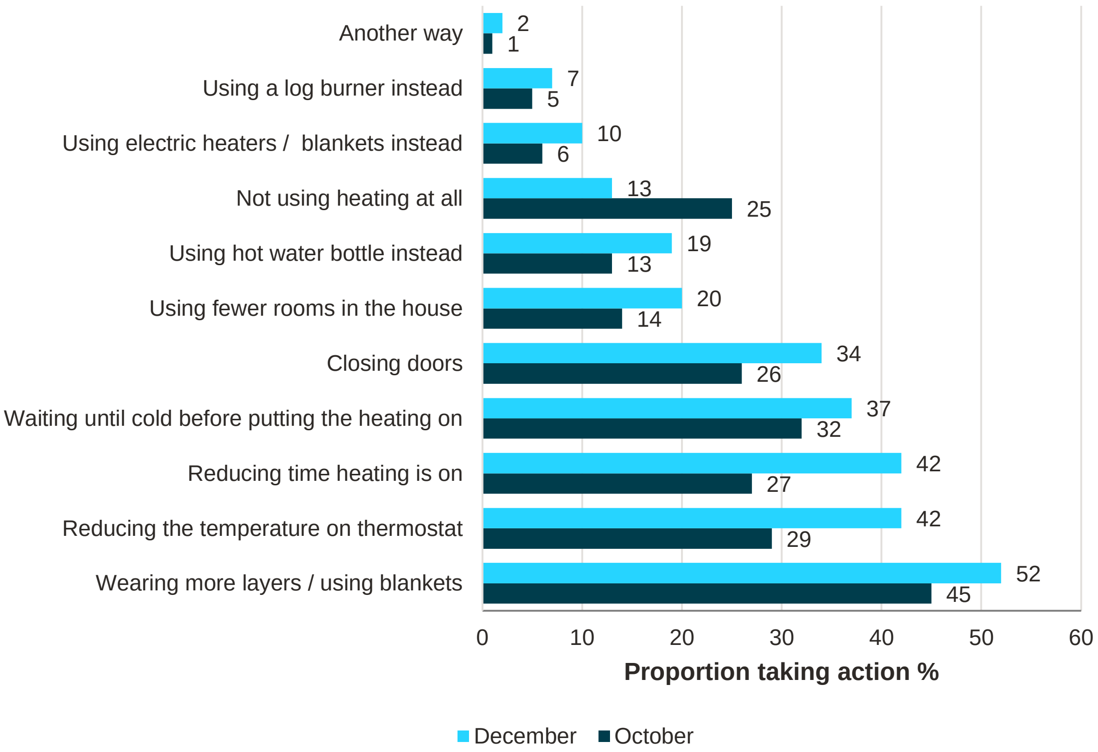
34 Office for National Statistics. 20 February 2023. *Impact of increased cost of living on adults across Great Britain: September 2022 to January 2023.*

35 Please see footnote 2 for the definition of fuel poverty that we use.

36 YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

37 UK Government. 17 July 2019. English Housing Survey live tables: Energy Performance.

Figure 9 The actions people are taking to specifically reduce heating usage



Source: Frontier Economics illustration of YouGov data[38]

Note: Fieldwork 9 – 11 December for December survey, 3 – 4 October for October survey

The proportion of people who were not using heating at all nearly halved (from 25% to 13%) while other actions to reduce heating usage became more popular, reflecting a change in how people were looking to reduce usage as the winter progressed.

The data suggests that people substituted other energy saving actions in place of not using their heating at all, as fewer people were prepared to go without any heating in the colder months. These actions include a mix of 'set and forget' actions as well as everyday behaviour changes. This suggests that gas consumption might face larger decreases over the winter period than electricity.[39]

2.3.3 Impact of actions

One of the key parts of our modelling work is attributing the impact of energy-saving actions to changes in household consumption. To help come up with some initial hypotheses to test, we want to understand the expected impact of energy saving actions.

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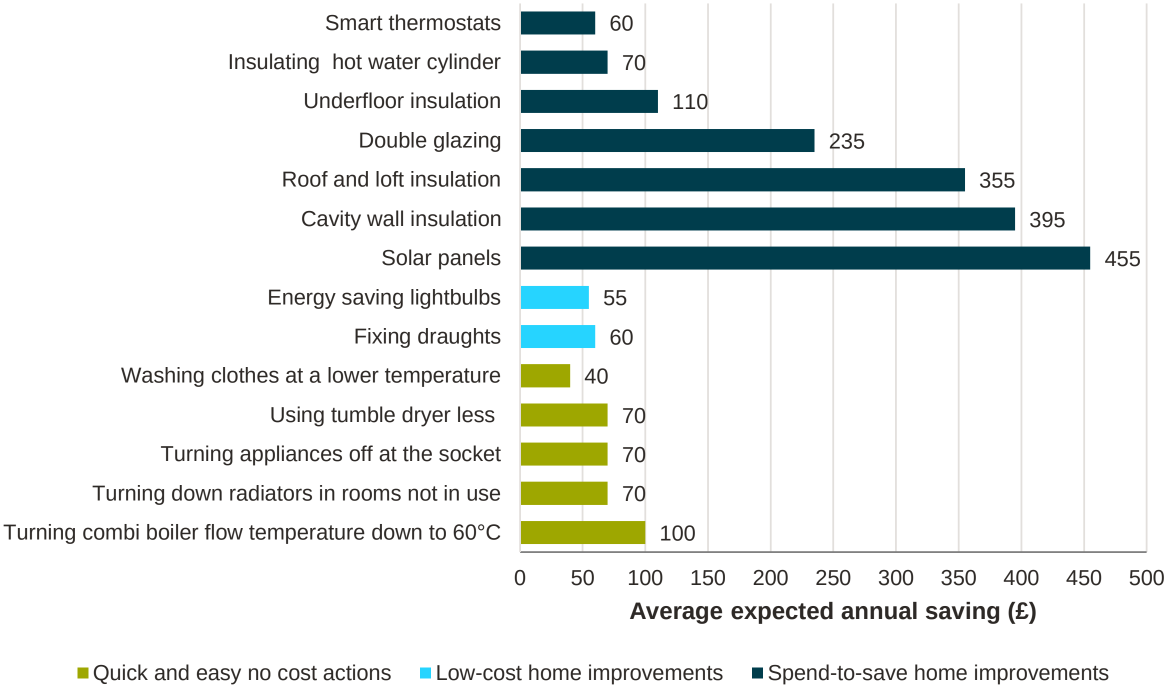
38 YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

39 This will depend on the proportion of households that heat their homes with electricity compared to gas or other types of fuel.

Where advice has been given to households on how to cut down energy consumption, it is often accompanied with estimates of expected average savings that each action could make over the course of a year. The UK Government provides tips for energy saving along with an estimate of the average expected saving that can be made by following an action. The estimates given are illustrated in Figure 10.[40]

Figure 10 Average expected annual savings from energy saving actions from Help for Households advice



Source: Frontier Economics illustration of UK Government Help for Households advice estimates.[41]
Note: Actions are grouped as they appear in the Help for Households advice.

At a high level, we see that the most effective actions in terms of money saved on energy bills tend to be higher cost, such as insulation and the installation of solar panels and double glazing. We also see that substantial savings can be made by implementing no-cost 'set and forget' actions.

However households' perceptions of actions to save energy is mixed. Research by the Behavioural Insights Team, published by the charity Nesta, finds:

40 There is however significant uncertainty involved in these estimates and the effects are likely to vary significantly by household.

41 UK Government. *Help for Households: Energy saving tips to save money.*

> *"Concerns about higher energy bills have pushed almost all households in the UK (98%) to try to save energy in at least one way. But despite most people trying at least one energy-saving measure, many still don't know which are the most effective."*[42]

According to its research, the perceived most effective action was air drying laundry (as opposed to using a tumble dryer) which is estimated to save approximately £70 annually. However, the estimated most effective action – turning the thermostat temperature down 2°C – could save £309 per year. Despite this, it was ranked fourth in terms of perceived annual impact by respondents. Taking showers instead of baths and turning off lights were both rated fifth highest for potential savings despite being the least effective based on estimated impact. People perceive there to be little variance in effectiveness of different actions, but in reality there are savings ranging from £16 to £309 a year for a given action.

This suggests that customers may choose to take actions that are less effective at reducing consumption. Therefore, we might observe some customers that take a large number of relatively ineffective actions will see consumption change less than a customer taking a small number of effective actions.

2.4 Summary of hypotheses

To answer our questions set out in Section 1, we need to take what we have learned in Section 2.3 and create some hypotheses which we can test in the modelling. The results of that modelling will be used to answer our questions.

Where possible, we have set out hypotheses at an overall level and for different customer groups based on our findings from the literature. However, where the literature is limited regarding energy saving actions they have taken (particularly in the context of customer groups), we have instead set out hypotheses based on reasonable assumptions regarding how the customer may act given their socio-economic group.

2.4.1 Actions taken by households

- Some actions (such as wearing more clothes) are intended to compensate for the impact of other actions which directly reduce energy expenditure (for example, turning down the thermostat). We would therefore expect all households that carry out such 'compensatory' actions to have carried out actions with a direct bill saving, although the reverse may not be true.

- People tend to prioritise actions that are technically easy. A number of the actions listed as 'quick and easy no cost actions' also appear to be the most popular actions taken according to survey evidence. A potential barrier to people taking the most effective energy saving actions may be technical understanding. People may lack the knowledge

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42 Almost all households have taken at least one energy-saving measure amid fear of permanently higher energy bills. Nesta. 03 January 2023. https://www.nesta.org.uk/press-release/almost-all-households-have-taken-at-least-one-energy-saving-measure-amid-fear-of-permanently-higher-energy-bills/

of how to best implement effective consumption minimising strategies such as ‘set and forget’ actions (e.g. reducing the temperature flow on their boiler). Although this could be because they are not aware of the potential savings this could bring, it could be due to these actions requiring more technical understanding than small everyday actions, such as reducing usage of lights and other electricals.

- While the evidence suggests that the majority of households are taking actions to reduce energy consumption, there are a proportion of households who may not take any (or will take relatively few) actions to reduce energy expenditure. The extent to which households do not take actions will depend on their income level, the amount of support they receive for paying bills and the type of dwelling they live in. Additionally, there will be some socio-economic groups with a greater propensity to maintain domestic energy expenditure, such as:
  - households with young children;
  - those with long term sickness, health or disability issues; and
  - households containing elderly members.
- However, households can only save energy relative to the previous year if they are able to take additional energy-saving actions. The households most likely to have previously taken energy-saving actions are those already in fuel poverty. Therefore, the extent to which households in fuel poverty prior to the cost-of-living crisis can take additional actions will depend on the extent to which they took energy-saving actions prior to winter 2022.

2.4.2 Impacts of actions on household consumption and bills

- The impact of any given action will not vary depending on the characteristics of customers living in that households but will depend more on the characteristics of the dwelling. However, housing types may be correlated with household demographics.
- The impact of customer bills will depend on the changes in consumption. Households with higher incomes will face large increases in their household bills if it is the case that they take fewer compensatory actions. However, households with lower incomes or in the socio-economic groups set out in Section 2.3.2 may face smaller increases in their household bills as a result of additional actions taken, as a result of financial support offered.
- The extent to which households make bill savings will depend predominately on reductions in their heating consumption versus the previous winter (which for the majority of households will relate to gas consumption), rather than reductions in electricity consumption.

- The increase in energy prices will move a substantial number of households into fuel poverty, despite the ability to take energy-saving and compensatory actions.

- Based on these hypotheses, we can assess what actions were taken by customers. We do this in section 3, which describes the characteristics of households that have responded to the online survey. We then analyse the energy-saving actions taken by all households and by household type. In section 4 we assess the extent to which these actions impacted consumption during the cost-of-living crisis, relevant to the estimated counterfactual consumption; and in section 5 we consider the impact on households and NGED.

3 Overall impact of the cost-of-living crisis on household consumption in GB

In the previous section we set out our framework for analysing changes in consumption and the overall hypotheses that we will use to test in the data to answer our key questions.

In this section we first describe the impact on energy consumption (and therefore bills) of the cost-of-living crisis across all customers in our sample.

We then break down the extent to which these changes have been driven by actions taken by customers (and reported in our survey). We set out the extent to which customers reported carrying out actions (such as turning down radiators) which may affect consumption. Then we analyse the impact of these actions, allowing us to determine how far these actions were able, on average, to mitigate the rise in bills.

Finally, we summarise the overall conclusions of this analysis. Table 1 below summarises our identified hypotheses together with a summary of our conclusion about their validity based on our analysis.

Table 1 Hypotheses relating to aggregate impact on consumption

Hypothesis	Conclusion
Households that carry out compensatory actions (e.g. wearing more clothes) will be more likely to carry out energy saving actions that cool the home (e.g. turning down thermostat when home).	**No.** As discussed in Section 3.3.2, 14% of customers who carried out any compensatory action did not carry out any energy saving actions that cool the home.
The reverse may not be true – i.e. households carrying out actions that reduce their level of heating may not always carry out compensatory actions.	**Yes.** As shown in Table 4, 19% of customers who carry out any energy saving actions that cool the home do not carry out any compensatory action.
People will tend to prioritise actions that are technically easy.	**Yes**. The most popular actions (as shown in Figure 15) tend to be the easiest, such as wearing more clothes rather than turning the heating on. Larger and more capital-intensive actions are done by a much smaller proportion of the population.
For a typical customer, the bill savings resulting from energy saving actions will be greater for gas than electricity.	**Yes**. As described in Section 3.3, there are more actions to reduce gas consumption that have a significant impact (and greater in

Hypothesis	Conclusion
	terms of pounds saved) than actions to reduce electricity consumption.
More households will enter fuel poverty this winter.	**Yes.** We find a large increase in fuel poverty, despite households taking actions to reduce consumption.

Source: Frontier Economics

3.1 Overall impact on household consumption and bills

To assess the overall impact on consumption, we use SERL data on individual-level smart meter consumption before the cost-of-living crisis to estimate a model predicting each customer's consumption had there been no external shock (Annex B describes this process in more detail). This counterfactual consumption was compared to the actual consumption recorded over the period October 2022 to December 2023 to infer the change in consumption caused by the cost-of-living crisis.[43]

The analysis shows that consumers responded to the increase in prices by reducing their consumption by 14% for gas and 8% for electricity (and this result for electricity consumption is despite the majority of customers using gas for heating).[44] This is a substantial reduction in energy consumption for households. However, even with this reduction in consumption and the support of the EPG, the scale of the price increases meant that bills faced by consumers in this period still rose overall by £75 for electricity and £150 for gas (after the effects of the EPG) over the three month period of our analysis.

We can illustrate the impact on bills.[45] Assuming that customers were on the price cap during winter 2021 and winter 2022 and received government support via the EPG, we have calculated an average bill for these two periods and have broken down the increase between:

- the impact of the higher energy prices had consumption not changed;
- the impact of the EPG on prices; and
- the mitigation of this impact caused by the reduction in consumption. [46]

43 The counterfactual consumption accounts for other variables that impact energy consumption such as temperature and sunlight.

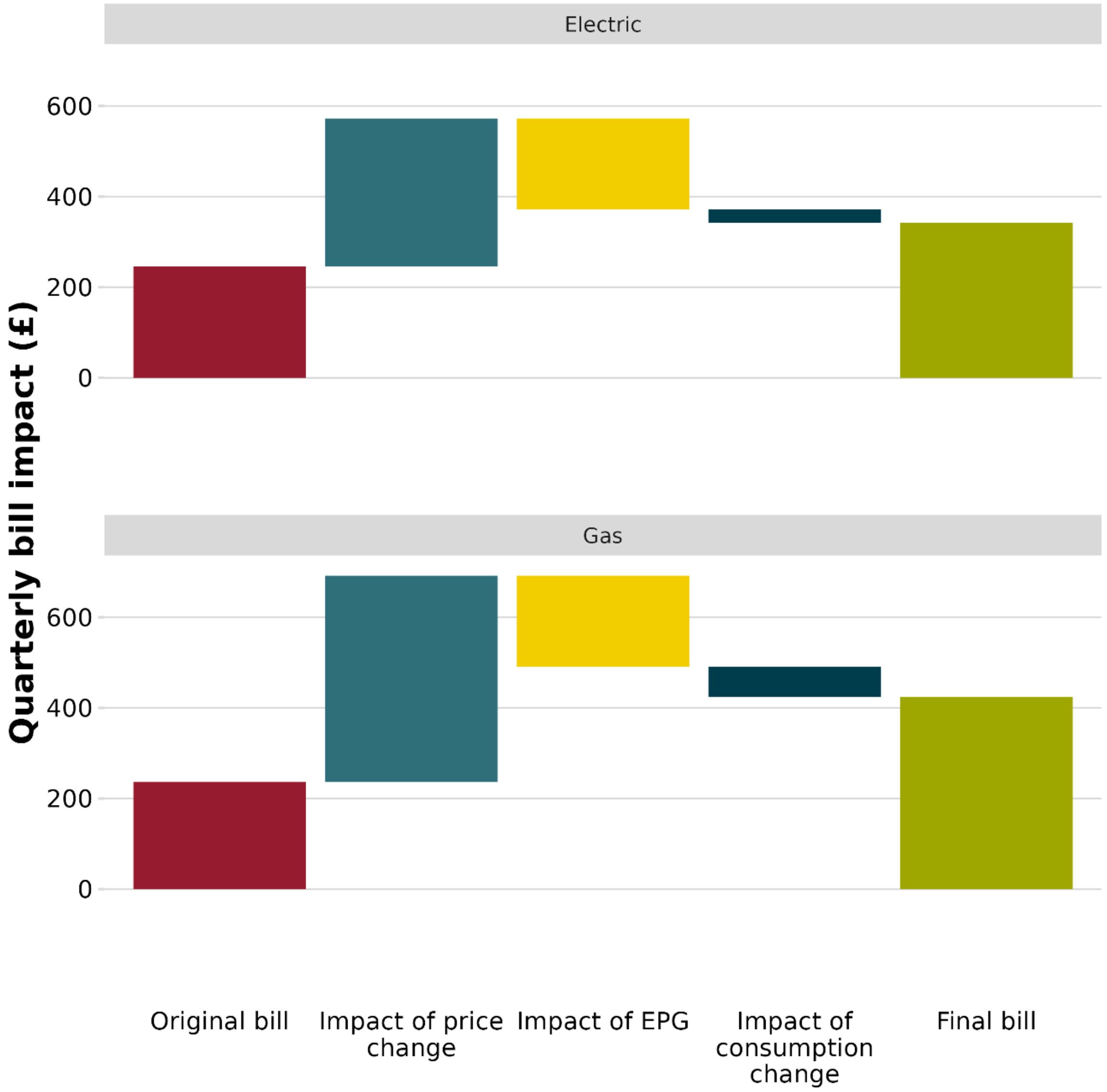
44 In Section 2.3 we note that previous studies found a 1% reduction in consumption for a 10% increase in price. Electricity prices rose 57% from Q2/Q3 2021 to Q4 2022, while gas prices rose 149% over the same period, which suggests the reduction in consumption was higher for electricity than in previous studies, but about the same for gas.

45 We have not adjusted the bill impact to reflect all the various support mechanisms that different households received throughout the crisis, therefore the bill impacts will likely overestimate the actual bills paid by households.

46 It is reasonable to expect the vast majority of households have faced the price cap in October to December 2022, since that was the cheapest available rate and the default rate. However there are likely a larger number of households who were on a rate lower than the price cap prior to the cost-of-living crisis. Therefore this calculation may understate the

This is shown below in Figure 11.

Figure 11 Average change in normalised household bills across all households for October to December 2022



Source: Frontier Economics analysis of SERL data

Note: To get a normalised bill, we scale consumption relative to the Typical Domestic Consumption Value. The Energy Price Guarantee (EPG) is the guarantee that provides a support rate discount to all households with a domestic gas and/or electricity contract. This was introduced on 1 October 2022 and reduced bills below the price cap level.

Households saved around £67 on gas bills as a result of energy saving measures and around £29 on electricity bills. While significant, it is noticeable that these savings are dwarfed by the impact of the EPG of £200 for gas and £200 for electricity. Even after both the EPG and

increase in household bills. The relative increase in prices in the intervening period is large compared to the difference between the price cap and average bill in that previous period, which suggests this impact would be small.

consumption reductions, the average net impact on customer bills is still a 30% increase for electricity and a 63% increase for gas for this three-month period. It should also be noted that the analysis only covers one quarter of the year and, importantly, it does not cover the impact for the whole winter period (i.e. it does not include the first quarter of 2023).

We consider the impact of these increasing bills on fuel poverty. There is a standard definition of fuel poverty used by the government.[47] We can estimate the level of fuel poverty using the information in the cost-of-living survey (described in Section 4.1) together with information on actual and predicted energy costs. This analysis can be used to identify households moving into fuel poverty. While the analysis is in line with the Fuel Poverty Methodology Handbook, there are some caveats to this analysis which may mean that some households are incorrectly identified.[48]

We find that the impact of increasing bills meant that the proportion of our sample in fuel poverty increased from 12.5% to 15.7%, a percentage increase of 25.6%. To adjust our quarterly bill increase into an annual analysis on fuel poverty we normalise consumption to an annual level using typical quarterly consumption estimated by Ofgem.[49] We are therefore assuming the price impact from October to December 2022 is maintained at the same level throughout the year. It is not yet known whether bills will fall below the level of the EPG over the course of this year. If they don't, this will be an under estimation of whether households enter fuel poverty.

It should also be noted that this is an estimation. Our sample may not be representative as the people who chose to complete the cost-of-living survey may be less likely to be on the edge of fuel poverty. Completing the survey requires time and effort, which might be more difficult for those working multiple jobs or keeping themselves and their family warm in tough circumstances. In any case, it is striking that the number of people in fuel poverty (at least temporarily) in our sample increased by over 25%.

3.2 Changes in energy consumption over time

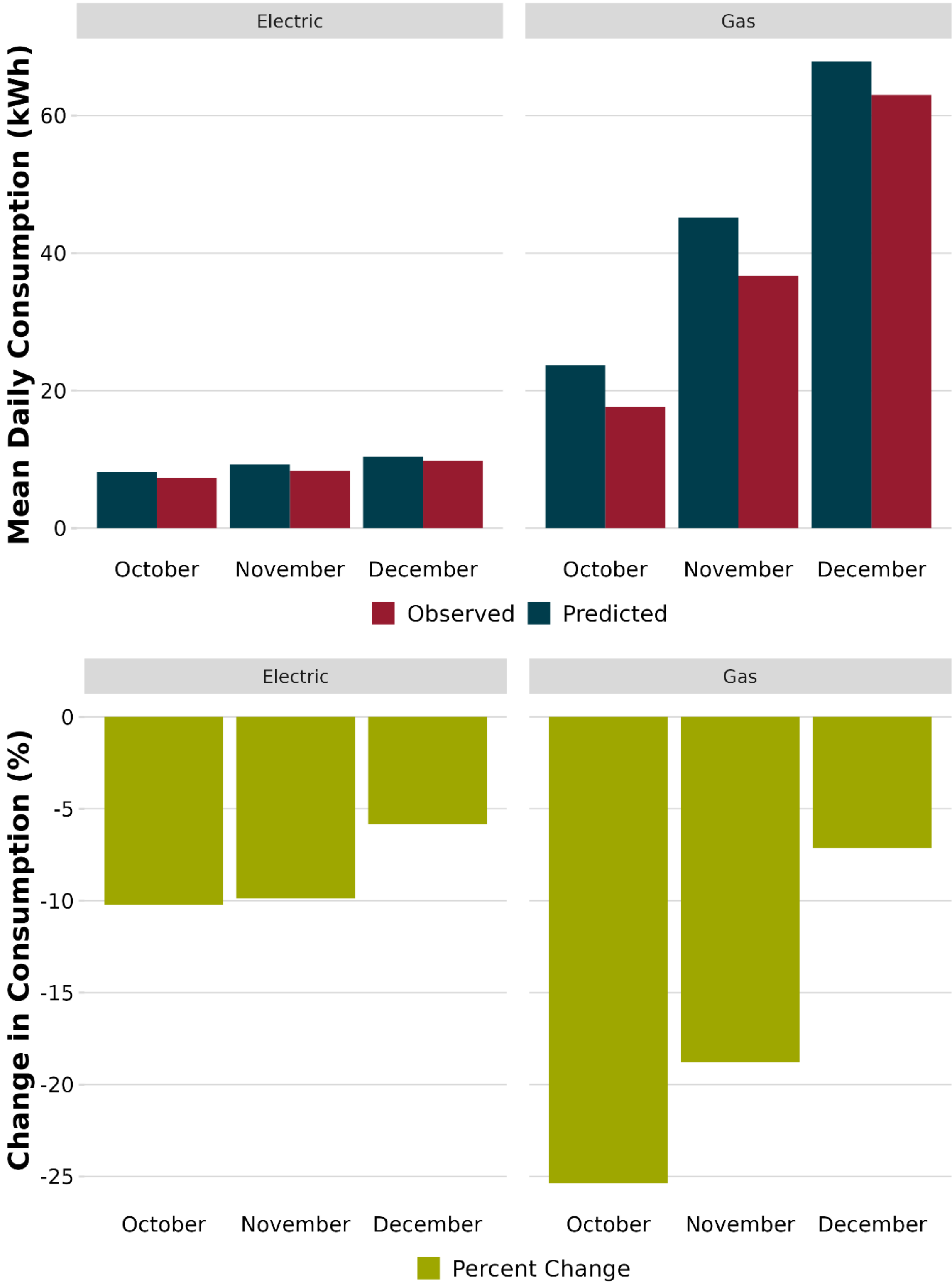
The previous two sub-sections considered the overall impact of consumption changes on bills and the extent to which households might have moved into fuel poverty. In this section we consider the variation in household consumption over time and across all customers. Figure 12 shows the effect on consumption changes over time.

[47] Please see footnote 2 for the definition of fuel poverty that we use.

[48] Fuel Poverty Methodology Handbook, Department for Energy Security and Net Zero, 2023; Some notable caveats include that we have to estimate housing spending using income estimates to the nearest £10,000 and we have to adjust the analysis to assess a quarterly impact on consumption (fuel poverty is typically calculated on an annual basis).

[49] Ofgem, Wholesale Cap Methodology Model

Figure 12 Observed and predicted consumption and the percentage difference for October to December 2022

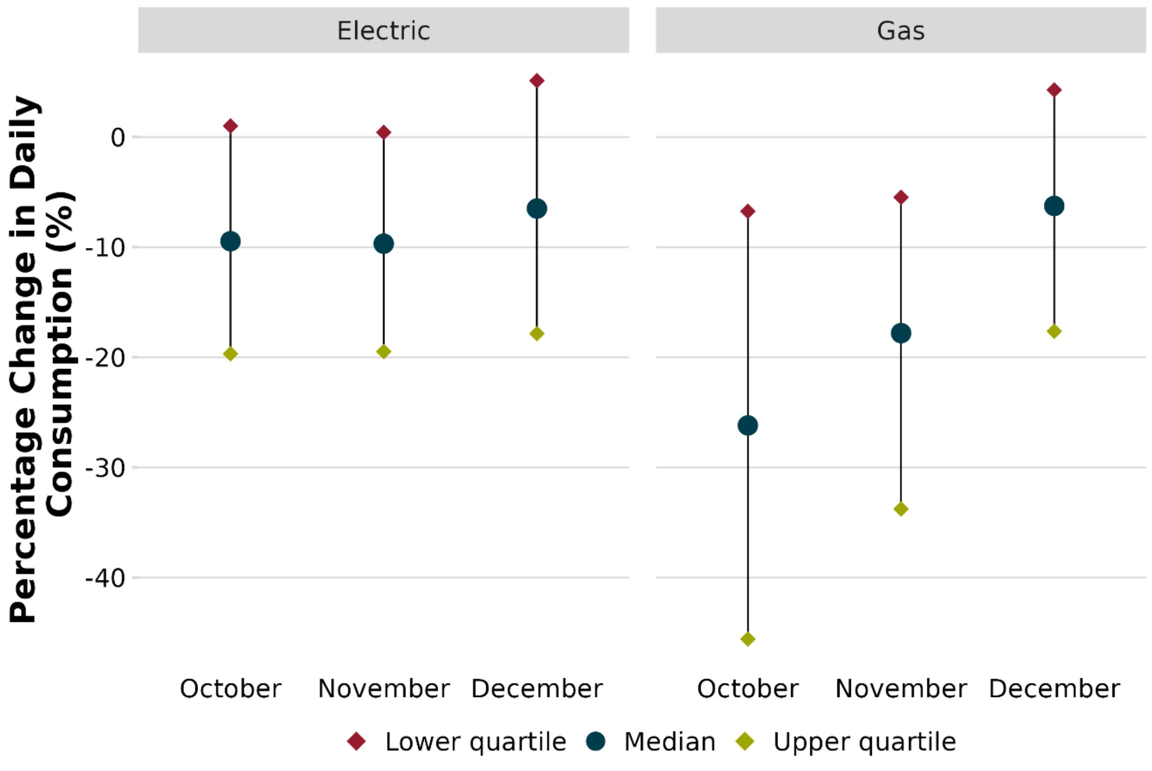


Source: Frontier Economics analysis of SERL data

In October, electricity and gas consumption decreased (as a proportion of predicted consumption) more than in December. These consumption decreases are large in both electricity and gas, although particularly large in gas. The changes had the biggest impact in October and November. For electricity this change is fairly constant with a 10% decrease in both months. For gas the percentage decrease has reduced from October to November (from around 26% to 18%) although the absolute saving is larger. In December, the fall in consumption is smaller than in October and November for both electricity and gas (both less than 10% decreases in consumption). We will investigate this effect further below.

This chart only considers the average household's change in consumption. We can observe distributions around the median by considering the upper quartile and lower quartile values, see Figure 13.[50]

Figure 13 Distribution of consumption changes for October to December 2022



Source: Frontier Economics analysis of SERL data

This shows that there are a significant group of customers who have made very large reductions in consumption over the period. For electricity around a quarter of households reduce consumption by more than 20%, There are also a similar proportion of households who did not change their behaviour, consuming around the levels that would have been

50 The median shows the value where there are 50% of observations either side. The upper quartile represents the value where 25% of observations have higher values; the lower quartile represents the value where 25% of observations have higher values. This can show the range of observations in the sample.

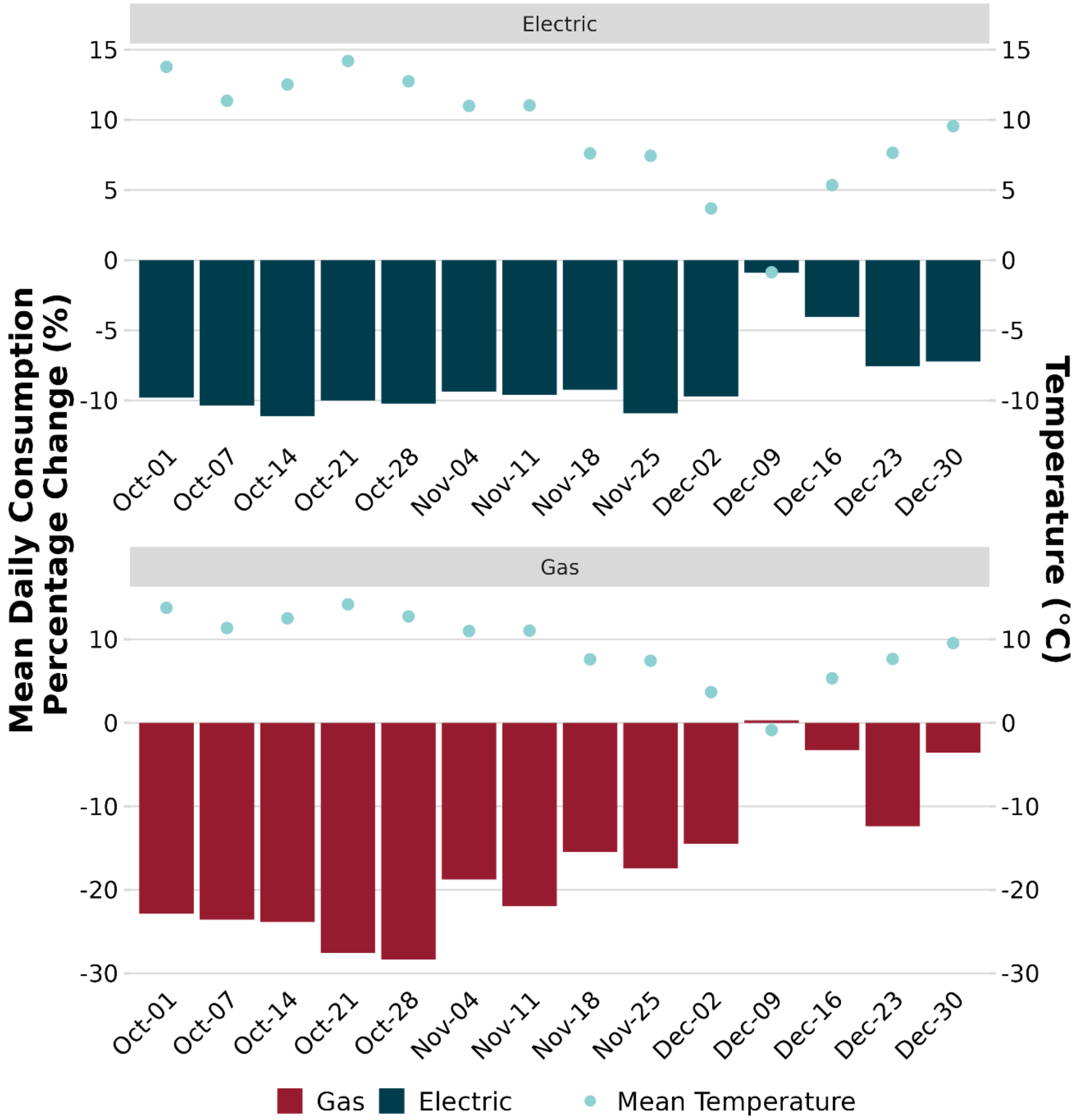
predicted, with a small uplift in December. This pattern remains largely stable over all months in the sample.

For gas we find that there is a very large change in consumption for a large proportion of the sample. In October, around a quarter of people reduced gas consumption by about 45%. However the proportion of the population making changes of this size reduced over time. This reduction is consistent over all cohorts over time.

This also shows the distribution of consumption changes varies between October and December. In October there is a wide distribution of consumption changes as some customers decrease consumption by a large amount while others decrease consumption by a smaller amount. By December the difference between the upper quartile and lower quartile is smaller.

Given this drop-off in response in December, we have looked in more detail at what may have caused it. Given the change is most obvious in gas consumption, it is likely to be related to an increased use of gas for heating, which may be caused by a drop in temperature. While the model already accounts for changes in temperature in its estimation of predicted consumption, the hypothesis here is that people are happy to live with cooler homes up until the point where the outside temperature drops below a certain level, at which point they revert to their historic behaviour. We can analyse this in more detail by plotting consumption and changes in consumption against temperature. Figure 14 shows percentage change in consumption and temperature on a weekly basis over the winter.

Figure 14 Observed and predicted consumption and temperature by week for October to December 2022



Source: Frontier Economics analysis of SERL data
Note: The dates given indicate the first day of each weekly period in the consumption data.

For gas, there is some link between temperature and households reverting to more normal behaviour. In the early period households are decreasing consumption by a large amount. But as temperatures get colder households start to revert back towards their predicted consumption. However once temperatures drop below zero households show larger changes back towards predicted consumption. In contrast, electricity consumption does not revert at all towards predicted consumption until the same point when the temperature drops.

This corresponds to what we found in Figure 9 where the proportion of households not using the heating at all fell from 25% to 13% from October to December. YouGov's findings suggest households continued taking energy saving actions over that period but during December it is much less likely that households went without any heating.

After that point, the weather became warmer and similar to the three weeks prior to the 9th December. However, consumption did not change back immediately and to the same level. This suggests changes in consumption may be 'sticky'. Once a household increases gas consumption in response to colder weather, they may not reduce gas consumption again in response to (relatively) warmer weather.

However, consumption might be driven by other factors. A good example of this is during the final week of the year, actual consumption is similar to predicted consumption. This final week coincided with the period between Christmas and New Year, which may explain why actual consumption behaviour appeared more similar to predicted behaviour despite an increase in temperature.

Given the data only runs until the end of December, which is associated with atypical household behaviour around Christmas and New Year, we do not know if the behaviour will revert to October and November consumption levels in response to temperature rises. As temperature changes over the winter it will be useful to understand which energy saving actions are maintained and whether consumption decreases are 'sticky' or not.

3.3 Actions taken by households

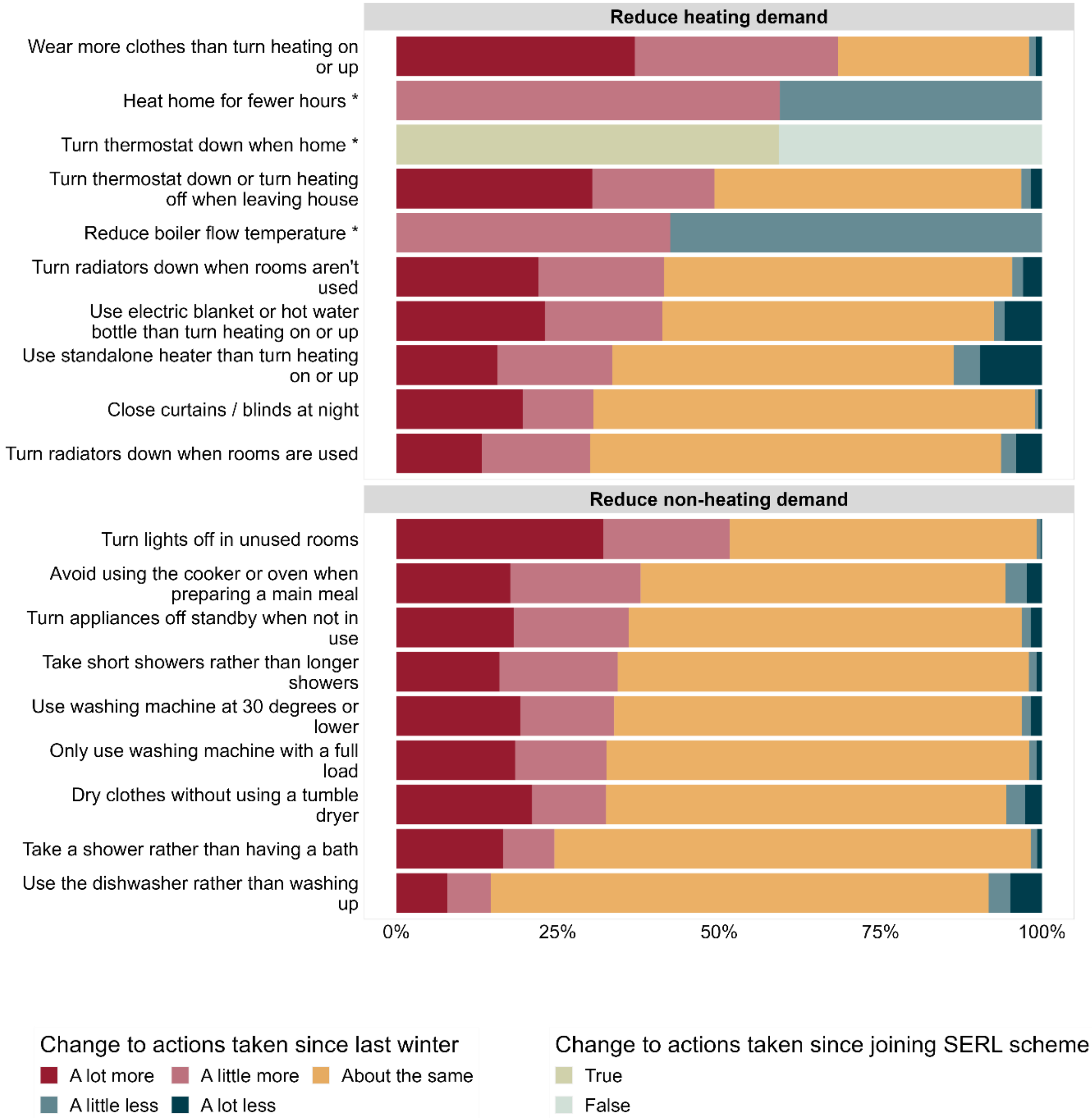
The decrease in consumption we report in the previous section was presumably due to actions taken by households and we want to understand what these were. To do this we commissioned a survey alongside UCL to understand household behaviours in winter 2022 (the Cost-of-Living Survey). There are two types of information we can summarise from the survey responses:

- **Actions undertaken by households**, where we ask whether they have taken various possible actions, with space for households to add additional 'free text' responses.
- **Household characteristics**, which could affect the response to the crisis, such as household composition or the extent to which they report being in financial distress.

In this section we focus on actions taken across all households rather than the household characteristics. The household characteristics are covered in Section 4. The survey was sent out in January. In total, we have received 5,827 responses, a response rate of approximately 45%. This is above typical survey response rates of this kind but below the response rate for SERL's previous survey during the pandemic (which was over 60%).

The survey asks respondents to what extent their household is taking actions to reduce energy consumption compared to the previous year. Figure 15 below shows the results, with the actions ordered by the proportion of households that responded 'a little or a lot more' to the relevant action.[51]

Figure 15 Actions taken by all surveyed households



Source: Frontier Economics analysis of SERL data

Note: 'Reduce boiler flow temperature' asked customers whether they had reduced the flow temperature of their boiler 'during this winter'. 'Heat home for fewer hours' was a binary question asking customers whether they are heating their home for fewer hours 'than in previous winters'. 'Turn thermostat down when home' has been constructed using the cost-of-living survey and the recruitment survey that customers complete when they joined the SERL scheme. Most households joined the scheme in 2019-2020.

51 In the Cost-of-Living survey, there were five possible responses to this question regarding energy-saving changes made since last winter. They are: 'a lot more,' 'a little more', 'about the same', 'a little less' and 'a lot less'.

Overall we find that around 95% of households reported taking at least one action to reduce energy consumption. The proportion of surveyed households taking action in the SERL survey is above the proportion of households taking action in the YouGov survey (see Section 2.3). It is worth noting that YouGov are also looking at actions taken above 'normal' usage, so we would expect results to be similar.[52] Of these, 'Wear more clothes when cold than putting heating on or up' is the most popular action where more than two-thirds of households have changed since last winter. The next most popular actions are 'heating the home for fewer hours' and 'turning the thermostat down when home', with around half of households taking these actions.

The least popular actions are 'taking a shower rather than having a bath' and 'using the dishwasher rather than washing up', with less than a quarter of households taking each action 'a little or a lot more' since last winter. [53]

Typically the most popular actions relate to reducing heating consumption while the least popular actions relate to reducing non-heating consumption. We find that 92% of households took at least one action to reduce heating consumption while 78% of households took at least one action to reduce non-heating consumption. However it is notable that non-heating actions tend to have a significant minority of households who are taking them more than previous winters.

A number of the actions in Figure 13 are also listed as quick and easy no cost actions on in the Help for Households advice.[54] They tend to be relatively popular too: reducing boiler flow temperature and turning radiators down in rooms that aren't in use are both taken more by over 40% of households (42% and 41% respectively). 36% of households turn appliances off rather than leaving them on standby more often than they did the year before. A similar proportion of households report that they are using the washing machine at lower temperatures (34%) and drying clothes without using a tumble dryer more (32%). Finally, 31% of households close their blinds and curtains at night more often than in 2021/22.[55]

We also find that these actions are far more extensive than larger home improvement actions. These are typically actions to improve energy efficiency or reduce bills through home investments, such as loft insulation, solar panel installation or improving window glazing. Around 11% of our sample took a large-scale home improvement action during the 12 months

52 For example, in the YouGov survey, 63% of households took action to reduce heating usage. On the other hand, 50% of households responding to the SERL survey have turned their thermostat down or turn heating off when leaving house 'a little or a lot more' since last year. 41% of SERL survey respondents have turned down radiators when rooms aren't used and 30% of respondents have turned down radiators when rooms are used. In the YouGov survey, 36% of households took action to reduce washing machine usage, whilst comparable values for SERL survey respondents are 32%-33%. The same proportion of households (38%) took action to reduce oven usage in the YouGov and SERL survey.

53 It is ambiguous as to whether this is an energy-saving action since it depends on how much washing up is being done by the dishwasher.

54 UK Government. 2023. *Help for Households, Energy saving tips to save money.*

55 Although not listed in the Help for Households advice, turning the thermostat down when leaving the house could be considered a quick and easy no cost action. 49% of households reported doing this more.

before the survey, which is during the period of significant price increases. Clearly these actions require more household investment, which is not available to all households, so we would expect these actions to occur at a lower rate than other quick and easy actions. However there is some evidence that there are more actions taken this year than in previous years. A report by the Energy Efficiency Infrastructure Group reported in 2019 that less than 1% of UK homes (170,000) were annually renovated with significant energy efficiency improvements.[56]

3.3.1 Impact of actions on consumption

In order to break down the extent to which the overall change in consumption (and therefore bills) described in section 3.1 was driven by actions taken by households, we have carried out a regression analysis which relates the change in consumption for a typical customer to the different actions they may have taken.[57] This analysis tells us the amount that a typical customer carrying out one action *and no other actions* would expect to save. As with the other bill figures in this work, the savings relate to the three months (October to December 2022) covered by this analysis.

Where a material number of customers carried out an action *less* than the year before, we have quantified the impact of this too.

For electricity consumption, we find that only a small number of actions have a statistically significant impact on electricity consumption, as shown by Table 2 (see Annex E for the full results of the regression including insignificant impacts).

Table 2 Impact of energy saving actions on electricity consumption during October to December 2022

Actions taken by household	Impact on electricity consumption (£ household bills)[58]
Using a standalone heater rather than turning heating on or up: doing this action less	-6.68

[56] Making energy efficiency a public and private infrastructure investment priority, Energy Efficiency Infrastructure Group, October 2019; https://www.theeeig.co.uk/media/1063/eeig_net-zero_1019.pdf

[57] We normalise consumption changes because bigger households may have larger changes in consumption as a result of having larger predicted consumption than a smaller household. Normalisation makes these changes in consumption across households more comparable. We normalise by equating each household’s predicted consumption to the Typical Domestic Consumption Value and then scaling actual consumption accordingly.

[58] The impact of each action on household bills in this table is different to the impact for the same action in Figure 17. This is because the impact in this table gives the expected impact on household bills from taking an action, whereas the impact in Figure 17. decompose the consumption savings across the whole sample of households into the actions taken. Therefore, the actions are scaled according to the proportion of households taking each action.

Actions taken by household	Impact on electricity consumption (£ household bills)[58]
Avoid using the cooker or oven when preparing a main meal	-5.11
Heat home for fewer hours[59]	-3.75
Using standalone heater rather than turn heating on or up	**+5.18**

Source: *Frontier Economics analysis of SERL data*

Note: *Positive impact on electricity consumption is interpreted as the percentage increase in consumption of that action of total impact. Note that using a standalone heater less (i.e. the top line of the table) is the electricity consumption associated with using a heater less. Using a standalone heater more is the electricity consumption associated with using a heater more.*

This shows that the action that affects electricity consumption the most relates to the use of standalone heaters. The implied impact of increasing (or decreasing) the use of standalone heaters on electricity bills is statistically significant but has a relatively modest impact. The overall impact on bills depends on the extent households, specifically those who use gas for heating, reduced gas consumption in conjunction with this action.

For gas consumption there are more actions that have a statistically significant impact, as shown by Table 3.

Table 3 Impact of energy saving actions on gas consumption during October to December 2022

Actions taken by household	Impact on gas consumption (£ household bills)[60]
Heat home for fewer hours	-33.00
Use electric blanket or hot water bottle than turn heating on or up	-16.32
Use standalone heater than turn heating on or up	-15.03
Reduce boiler flow temperature	-11.21

59 This is the impact on electricity consumption of heating the home for fewer hours when considered across all households. If we consider the impact on electricity consumption only from households who have electric heating, the value in the table would likely be an underestimate of the impact for those households.

60 The impact of each action on household bills in this table is different to the impact for the same action in Figure 18. This is because the impact in this table gives the expected impact on household bills from taking an action, whereas the impact in Figure 18. decompose the consumption savings across the whole sample of households into the actions taken. Therefore, the actions are scaled according to the proportion of households taking each action.

Actions taken by household	Impact on gas consumption (£ household bills)[60]
Turn thermostat down when home	-7.01
Avoid using the cooker or oven when preparing a main meal	-6.24
Dry clothes without using a tumble dryer	**+6.00**
Turn lights off in unused rooms	**+6.93**
Turn thermostat up when home	**+10.81**

Source: *Frontier Economics analysis of SERL data*

Note: *Positive impact on electricity consumption is interpreted as the percentage increase in consumption of that action of total impact.*

There is a mixture of actions that are associated with increases and decreases in consumption.

Heating the home for fewer hours, turning the thermostat down and reducing the boiler flow temperature will all have a direct impact on gas consumption. This can be seen from the figures above, where the impact of these actions varies from a bill reduction of £7.01 to £33.00 over the three-month period.[61]

There are other actions that appear to have a statistically significant impact on gas consumption. Avoiding using the cooker is associated with a reduction in gas bills on average – likely due to the presence of households with gas ovens. In addition 'dry clothes without using a tumble dryer' and 'turn lights off in unused rooms' appear to be associated with an increase in gas bills. The tumble dryer result might derive from households drying clothes on radiators instead and running their central heating for longer.

The lighting result is unintuitive; however one hypothesis is that households were compensating on electricity usage in order to use more gas.[62]

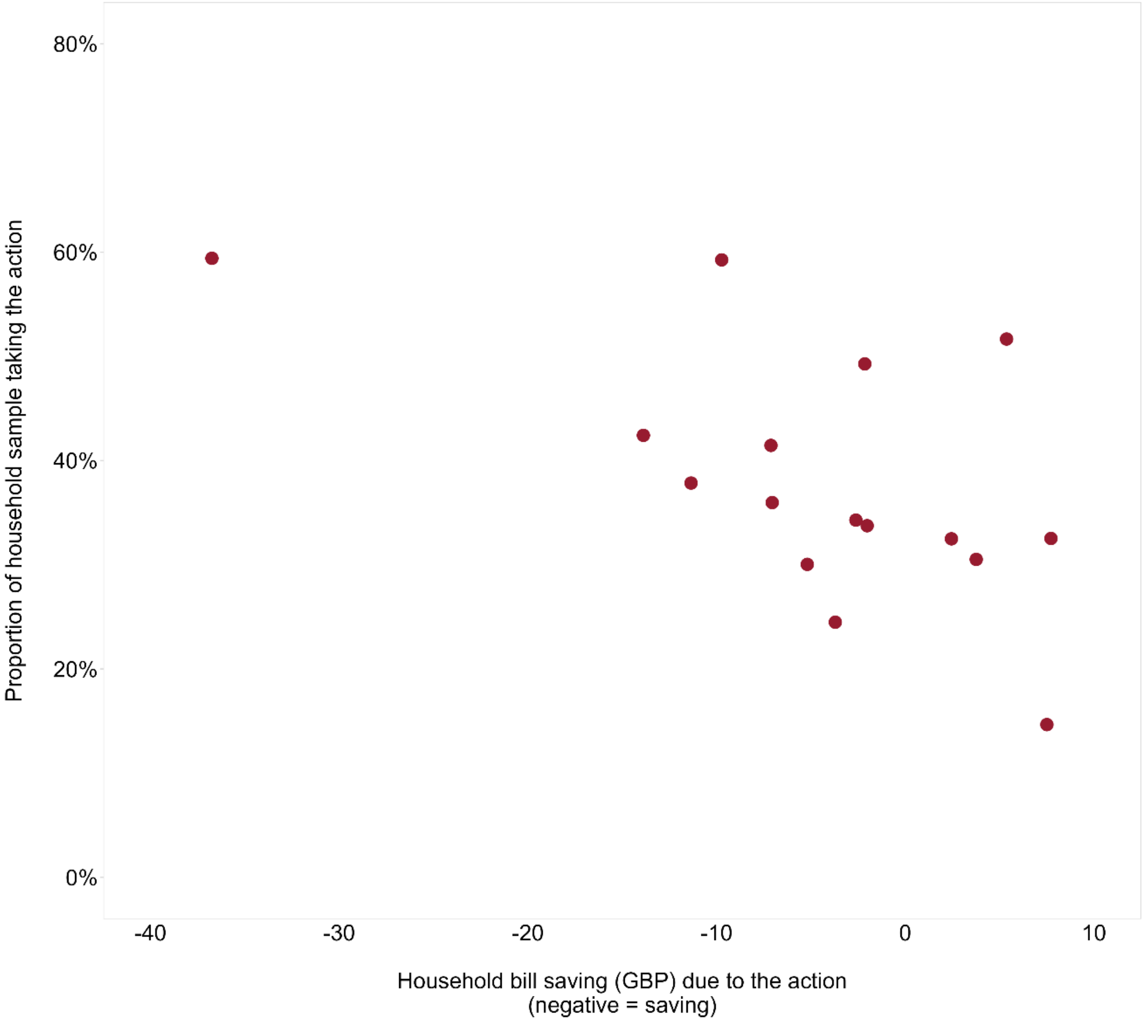
In Section 2.3.3 we found evidence, by Nesta, which showed that using a tumble dryer less during warmer months could save households on electricity bills. However Table 3 shows that using a tumble dryer is associated with an increase in gas bills (and is not associated with a decrease in electricity bills). This result might derive from households drying clothes on radiators instead and running their central heating for longer. This illustrates the interaction between changes in electricity and gas consumption and why it is important for households to understand which combination of actions are most likely to be effective in saving on bills.

61 A trial by Nesta illustrated that households can save around 8% on their annual gas use by temperature the boiler flow temperature. This is slightly higher than our estimated impact. Source: Nesta, Testing boiler efficiency advice with households, 2023

62 We have tested the robustness of this result by interacting it with other actions and looking at the result across customer groups, and the result persist in both of these cases. The result also persists when we test it on split samples of the data.

We can illustrate the popularity and effectiveness of each action, see Figure 16.

Figure 16 Proportion of household sample carrying out actions and the impact of actions on bills



Source: Frontier Economics analysis of SERL data

This analysis shows that, in general, there is a correlation between the effectiveness of actions (in terms of estimated bill impact) and the popularity. The action which saves the most money (heating the home for fewer hours) is also one of the most popular actions. However other popular actions (such as switching lights off when leaving rooms) are much less effective than other less popular actions. And there are some actions (e.g. turn thermostat down or turn heating off when leaving house) that are more popular than the second most effective action, which is reduce boiler flow temperature. Therefore the effectiveness of household actions is mixed, as we found in Section 2.3.3.

We can see that there is more scope for actions to reduce gas consumption in comparison to electricity consumption: there are both more actions to undertake and those actions tend to have a larger impact. This might be the reason that we observe overall gas consumption falling more than electricity consumption. The majority of changes to gas consumption relate to changes in heating demand – we explore the different ways that households compensate for this.

3.3.2 Actions taken to compensate reducing heating demand

We want to understand to what extent households that take action to reduce their heating are able to compensate for this loss of heating, as set out in our first hypothesis in Section 2.4.1. To do this, we consider the set of compensatory actions taken by customers. These actions are those designed to keep individuals warm rather than the whole house and include:

- wearing more clothes when cold instead of putting the heating up;
- using a standalone heater when cold instead of putting the heating up; and
- using an electric blanker or hot water bottle when cold instead of putting the heating up.

Two of these compensatory actions appear in the regression analysis: using an electric blanket or hot water bottle and using standalone heaters. These results show that if consumers were to carry out compensatory actions that use electricity (particularly the use of standalone heaters) they may save money overall given that the increased electricity bills associated with these actions are outweighed by the associated reduction in gas bills. This shows that heating an individual, rather than the entire house, is likely to save households money. If households can fully mitigate discomfort through compensatory actions, then this is an effective way of reducing energy bills.

In Table 4, we consider the proportion of customers that carry out compensatory actions to warm themselves up given that they carry out energy saving actions that cool the home. For a given energy saving action, we can see the extent to which they took the energy saving action and the extent to which they took each of the compensatory actions. If a household takes energy saving actions but not compensatory actions, it is more likely that the individual is cold. Actions highlighted in dark red are taken the least while actions highlighted in dark blue are taken the most. Given that the cost-of-living survey asked customers whether they have taken compensatory actions more or less compared to last winter, it should be noted that customers may not say they are taking the action more this winter if they were already taking it last winter.

Table 4 Proportion of households that carry out compensatory actions given that they carry out energy saving actions

Action taken to reduce heating consumption	Wearing more clothes	Using a standalone heater	Using a hot water bottle or electric blanket	Taking any compensatory action
Heat the home for fewer hours	81%	28%	41%	86%
Turn radiators down when rooms are used	87%	32%	46%	91%
Turn thermostat down when home	73%	23%	34%	78%
Any action to reduce heating consumption	76%	25%	36%	81%

Source: Frontier Economics analysis of SERL data

Note: 'Any actions to reduce heating demand' is a composite action that refers to households that do at least one of the following actions: 'heat the home for fewer hours'; 'turn radiators down when rooms are used'; or 'turn the thermostat down when home'.

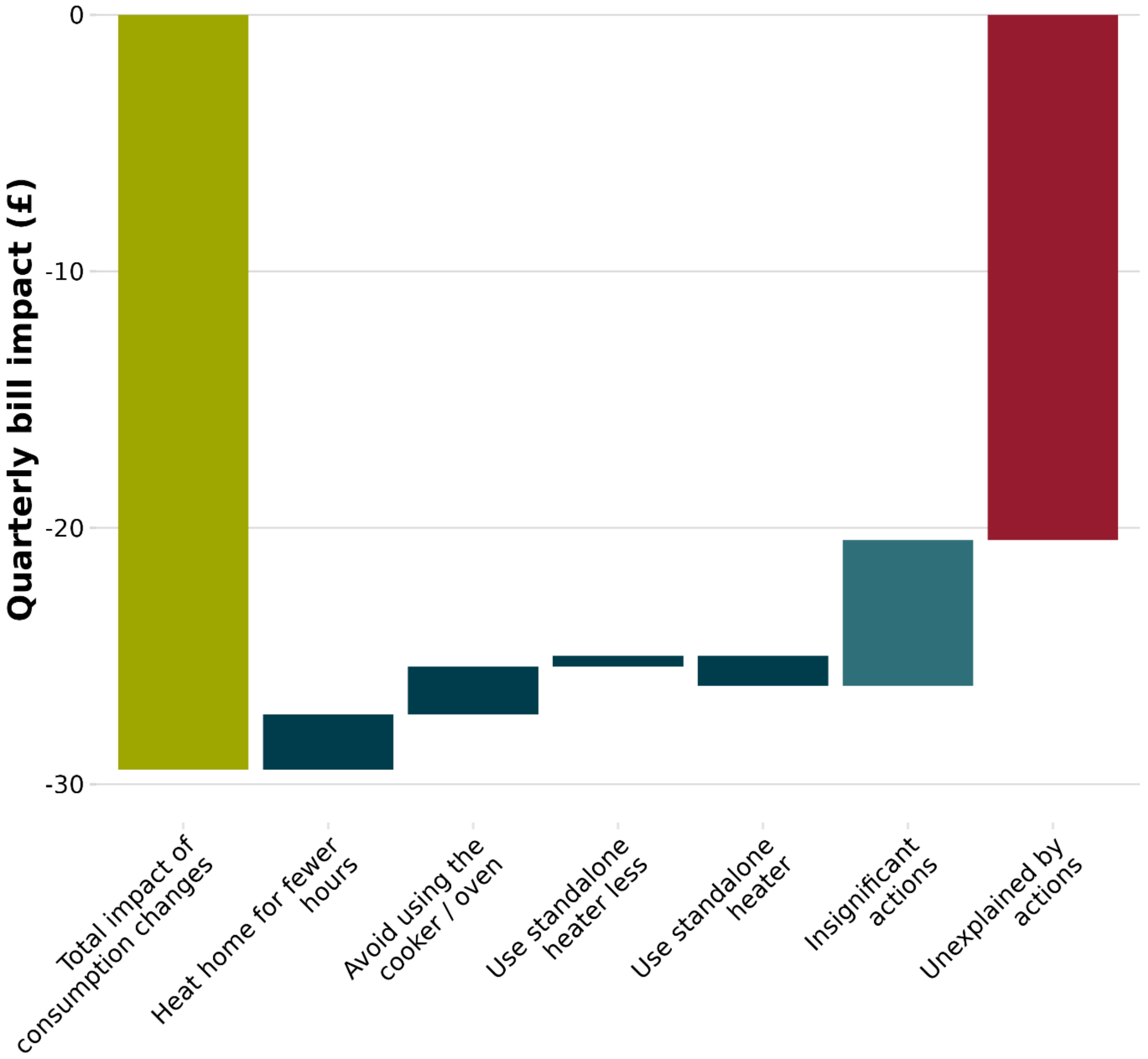
We find that the majority of households taking actions to reduce heating consumption are taking actions to compensate for reduced heating. Specifically households are most likely to compensate by wearing more clothes and are least likely to use a standalone heater. However there are around 19% of households who take actions to reduce heating consumption but do not take compensatory actions. Households who do carry out these compensatory actions may experience reduced comfort levels, although this depends on whether they were previously overheating their homes.

We also analyse the reverse, whether households that take compensatory actions also take actions to reduce heating consumption. We find that the vast majority of households (86%) who take compensatory actions also take actions to reduce heating consumption. Therefore, 14% of households are taking compensatory actions but not taking any actions to reduce heating consumption. These households may not be able to take additional actions to reduce heating demand because of preferences around their heating or because of changing household circumstances that are unobserved in the data. For example, they have an additional vulnerable person in their household (e.g. an elderly relative staying with them, or a young child).

3.3.3 Impact of actions on bills

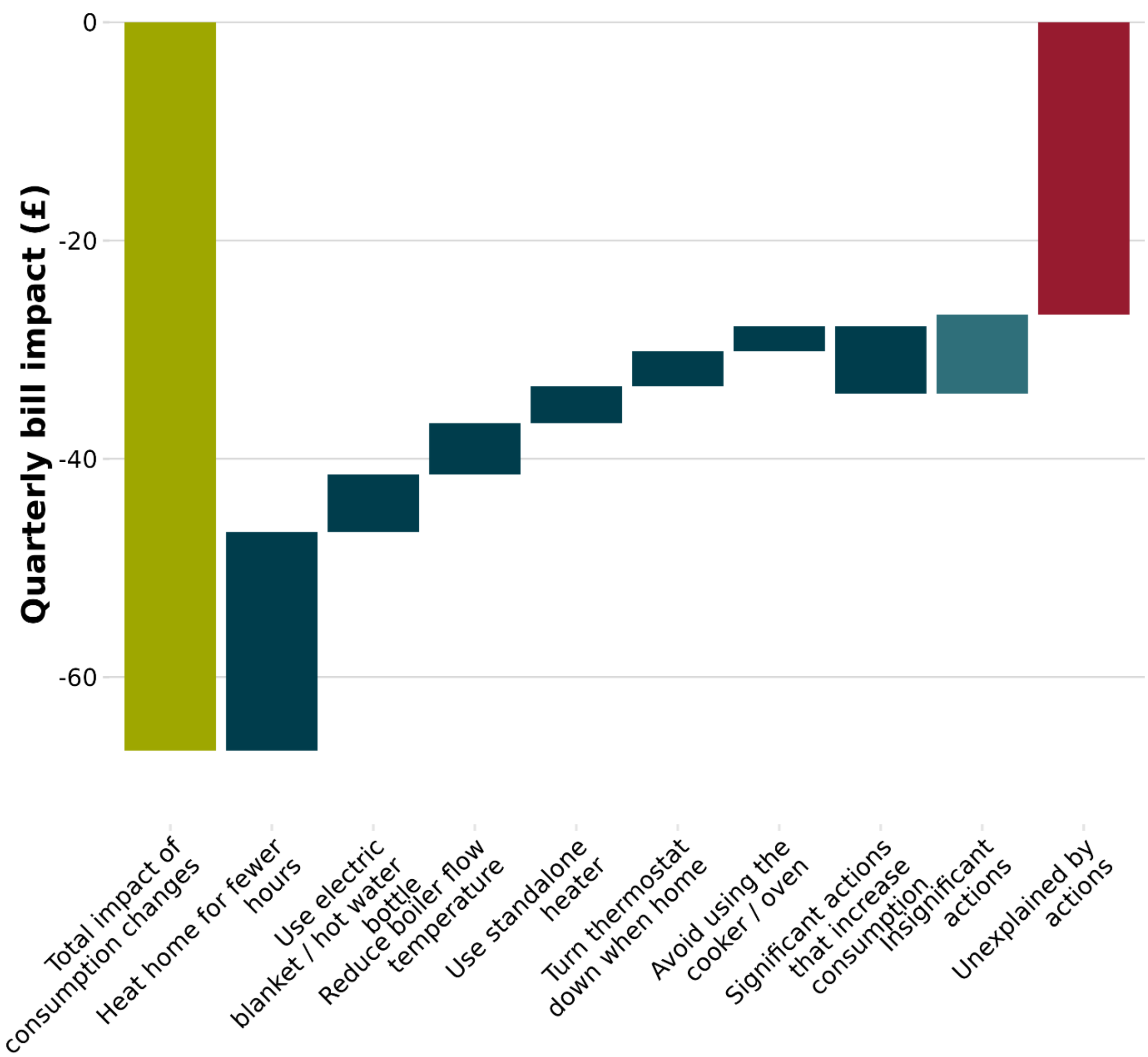
We can summarise the impact of actions on overall bills. Figure 17 shows the impact on electricity bills while Figure 18 shows the impact on gas bills. These figures are for the sample as a whole, therefore an action may appear to have a large effect due to a combination of the action itself being effective, and a large proportion of households taking it.

Figure 17 Impact of actions of quarterly electric bills



Source: Frontier Economics analysis of SERL data

Figure 18 Impact of actions on quarterly gas bills



Source: Frontier Economics analysis of SERL data

There is a distinct difference between the impact on gas and electricity bills. Around half of the gas bill impact can be explained through the actions that we showed had a statistically significant impact on consumption. A large majority of the remaining impact on gas bills was through factors unexplained by energy-saving actions. For electricity, only a third of the bill impact can be explained by the actions in our survey.

While two thirds of the impact on electricity bills is unexplained by actions, there are a number of potential explanations for this. For example, there are likely to be some household changes not picked up by the regression analysis (such as household composition changing over the

12 months between the model training period and the actual consumption period).[63] Our survey is also reliant on self-reporting actions, which might not have been reported accurately particularly as the survey was filled out in January and February 2023 about behaviours that occurred in October to December 2022.

The analysis presented in Figure 17 and Figure 18 shows the savings associated with the actions of all households that registered gas and electricity consumption, respectively. However, as we saw in Section 3.2 this masks a large range of responses. If we look at the top 25% of households that change their gas consumption the most, we see that they take on average two more actions than the average household. For electricity households this is one additional action compared to average. This translates into a bill impact saving of £109 for those top 25% of gas households and £50 for electricity. This is almost double the savings made than the average household.

We can also estimate the impact for households if they took every single action listed. If households took all actions that reduce energy consumption, this would be associated with £360 bill saving, which would reduce the typical bill customers paid for October to December 2022 by over a third. Of this, the vast majority of savings would be from changes to gas consumption (£334) while only a comparatively small amount of savings are available from changes to electricity consumption (£26).

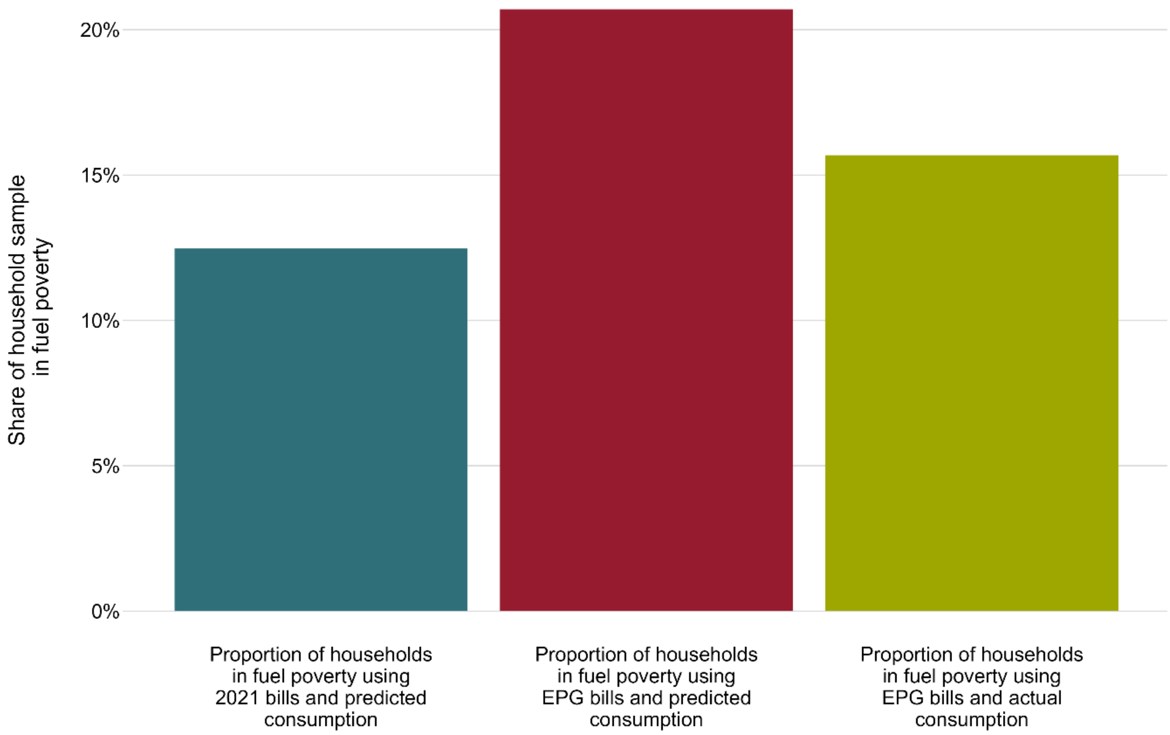
While this suggests there are large savings to be made from changes to gas consumption, it is not necessarily advisable for households to make such large changes to heating consumption. Instead, households might be advised to take a combination of actions that save electricity, reduce heating when not in the home and compensatory actions temporarily instead of heating the home. Taking these set of actions, it might have been possible for typical households to save around £206 on their bills from October to December 2022.[64]

Changes in consumption can help offset the impact of increasing prices, particularly for those struggling to pay bills. We can assess the impact of taking actions and changing consumption on fuel poverty. Figure 19 shows how the proportion of households in fuel poverty was affected by the cost-of-living crisis. The blue bar shows the level of fuel poverty had there been no price increases (and consumption was as predicted for each household). The red bar shows the level of fuel poverty because of prices increasing to the EPG level, but assuming consumption did not respond. Finally the green shows the level of fuel poverty because of prices increasing and households responding by changing consumption.

63 ‘Training period’ refers to the time period covered by the training data that is used to create the counterfactual data (See Annex B – Counterfactual methodology).

64 This is an illustration of the benefits but is not a precise estimate as we do not account for potential interaction effects between variables. For example, the impact associated with heating the home for fewer hours would be lower for customers who also turn down their thermostat.

Figure 19 Estimated proportion of household sample in fuel poverty predicted bills, counterfactual bills and actual bills



Source: Frontier Economics analysis of SERL data

Note: The blue bar shows the fuel poverty level using 'predicted bills', which refers to bills calculated using predicted or counterfactual consumption and where we assume tariffs are at the price cap. The red bar shows the fuel poverty level using 'counterfactual bills', which is the same calculation as the blue bar except that we now calculate bills using energy prices as set out by the Energy Price Guarantee. The green bar shows the fuel poverty level using 'actual bills', which is the same calculation as the blue bar except that we now calculate bills using smart-meter consumption data. However, this is still an estimation as we have not deducted the value of support schemes such as the Energy Bills Support Scheme (see Section 2.1).

The difference between the red bar and the green bar is the impact of changing consumption on fuel poverty. As a result of changes in consumption (of which a significant amount can be explained by actions) around 4% more households avoided fuel poverty. While it could be interpreted as a positive sign that actions are helping households avoid fuel poverty, there are a number of other implications. First, the aggregate impact of actions on household bills appears small (see Figure 11) but appears to impact a large number of customers on the edge of fuel poverty. This suggests that the households taking more actions are likely to be those struggling with their energy bills the most. Secondly, it also illustrates the limitations of a blunt measure of fuel poverty. There are many households who, according to our estimates, have avoided fuel poverty because of actions taken. However these households may be underheating their homes. Therefore the fuel poverty statistics may be understating the issues and impacts of the cost-of-living crisis on households.

3.4 Conclusions

There are a number of important conclusions that we can draw from this analysis.

There was a large reduction in gas and electricity consumption during the three-month period in our study. The reduction in consumption was larger and more variable in gas (14%) compared to electricity (8%), but it was still a large change for both. Changes in heating behaviour were a material driver of this.

Households saved around £67 on gas bills as a result of energy saving measures and around £29 on electricity bills from October to December 2022. While significant, these savings are dwarfed by the impact of the EPG of around £200 on gas and £200 on electricity. Even with both the EPG and consumption reductions, the average net impact on customer bills is still a 30% increase for electricity and 63% increase for gas for this three-month period.

We find that the impact of increasing bills meant that the proportion of our sample in fuel poverty increased from 12.5% to 15.7%. This is a significant increase that could have been even larger if households close to fuel poverty had not taken actions to reduce consumption.

There was significant variation in consumption across the period. Changes in electricity and gas consumption were initially large but became smaller over time. This is particularly noticeable in early December, coinciding with a big drop in temperature. However since our data ends at the year end, we have not been able to investigate whether the lower-level response rates persist even when the temperature increases.

These aggregate changes mask the fact that some households did a lot to change their consumption and some did very little. For electricity around a quarter of households reduce consumption by more than 20% while there are also a similar proportion of households who did not change their behaviour, consuming around the levels that would have been predicted. For gas we find that there is a very large change in consumption for a large proportion of the sample: in October, around a quarter of people reduced gas consumption by about 45%. However the proportion of the population making changes of this size reduced over time.

Overall we find that around 95% of households take at least one action to reduce energy consumption. Customers were more likely to carry out actions that reduce heating demand than actions that reduce non-heating demand. These actions also tended to be more effective. While most of these actions were low cost and simple to undertake, around 11% of our sample took a large-scale home improvement action during the 12 months, which is higher than the literature would have predicted.

The most effective energy saving action was to heat the home for fewer hours (which saved customers on average £33 in the 3-month period). Reducing boiler flow temperature and turning the thermostat down when home were the next most effective measures. It is notable that reducing the boiler flow temperature (which requires some technical knowledge of the heating system) is carried out by a greater proportion of customers than five other actions that reduce heating demand and all but one action that reduce non-heating demand.

There is also good evidence that those that chose to heat themselves rather than their home were able to reduce their energy consumption further and save additional money. Indeed, using a hot water bottle or an electric blanket provided the second highest saving associated with all actions (at £16.32 for the 3-month period). There is also evidence that those that used standalone heaters managed to save enough money on their gas bills to compensate for the increase in electricity costs through use of the heaters. If households can fully mitigate discomfort through compensatory actions, then this is an effective way of reducing energy bills.

It is not clear that those that reduced their use of tumble dryers saved money overall. In this analysis we found that people who used their tumble dryer less did not save on electricity bills and seemed to increase their gas consumption, spending more in total. This could be because they were spending more on heating their homes to dry their clothes. This illustrates why it is important for households to understand which combination of actions are most likely to be effective in saving on bills.

One in five households are reducing heating consumption but not compensating for this in other ways. The extent to which this is concerning depends on whether households were previously overheating their homes.

4 The impact of the cost-of-living crisis by household group

The previous section looked at the effect of the cost-of-living crisis on bills across all households. However this can potentially mask big differences between household types. Indeed, Section 3.2 has already shown that the overall impact on consumption varied widely across customers. This section looks to identify those differences between household groups (including households in vulnerable situations) and the average household, analysing the differences in consumption, bill impacts and actions between each group. We focus on households in vulnerable situations and other groups of particular interest to NGED, as outlined in Section 2.3.2.

4.1 Overview of household groups to be considered

As discussed in Section 3.3, the Cost-of-Living survey contains information on actions and household characteristics. The household characteristics that were asked about can be summarised into the following categories:

1. **Accommodation**. This includes questions regarding the type of central heating in the home, whether the home has energy sources such as solar panels and whether the home has energy efficiency features such as insulation.
2. **Income**. This includes questions regarding household income and the ease with which the household can meet heating costs.
3. **Household members**. This includes questions regarding the size of the household, the age of household members, their working status (e.g., working, retired, student) and the extent to which working members of the household work from home.
4. **The survey respondent**. This includes questions regarding how well they are managing financially and about their feelings on aspects of their life.

Based on the information available in the survey we can proxy for the set of relevant household groups that we consider based on the literature review in Section 2.3.2. The resulting groups are as follows:

Households in vulnerable situations

- **Households on the priority services register**:
  - **Households with elderly members**: Households with at least one member who is over 75 years old.
  - **Households with young children**: Households with at least one child aged between 0 and 5 years old.

  - **Households with members that are long term sick or disabled**: Households with one or more members who are not working because of health conditions.

- **Households who might be in financial difficulty**:

  - **Whether or not the household is 'financially struggling' or 'just about getting by'**: There is a survey question regarding whether households are 'managing financially'. We define customers who rate themselves as not managing well financially as 'financially struggling'. This can be used as a proxy for being financially vulnerable. In addition, we also consider households who rate themselves as 'just about getting by'.

  - **Households with pre-payment meters**: Households that respond to say they pay for energy via a pre-payment meter. We categorise households separately for electricity and gas. We consider these customers separately since they may have struggled more than others to access the EPG payments and may choose to self-disconnect.

  - **Households in rented accommodation or social housing**: Households responding to the survey indicating they live in rented accommodation or social housing.

Households with persistent effects from the pandemic

- **Working status and working from home habits**: Households indicating they work from home all the time or some of the time.

Other relevant households

- **Households with electric heating**: Households that heat their own home through power, either through electric resistive heating, a heat pump, or another method. We add this to the above list since it will be helpful for NGED to understand behaviours associated with electric heating. We also specifically consider households with heat pumps.

Each of these household groups is analysed in detail in Annex D . Note that there is not a separate group of fuel poor customers, as we will consider households in fuel poverty within each of these household groups throughout this section.

There is overlap between different household groups: some households may appear in more than one group. For example there are likely to be many financially struggling households that also use pre-payment meters, and so the results for pre-payment households will be driven, to an extent, by the fact that some are financially struggling. However the purpose of this analysis is to determine if the crisis had a different impact on different broad groups of households, rather than attempting to unpick the impact of individual household characteristics.

We have hypotheses that focus on household groups, as described in Section 2.4.1. We will answer these in this section, as well as explore other impacts of the crisis on household groups.

Table 5 Hypotheses relating to household group impact on consumption

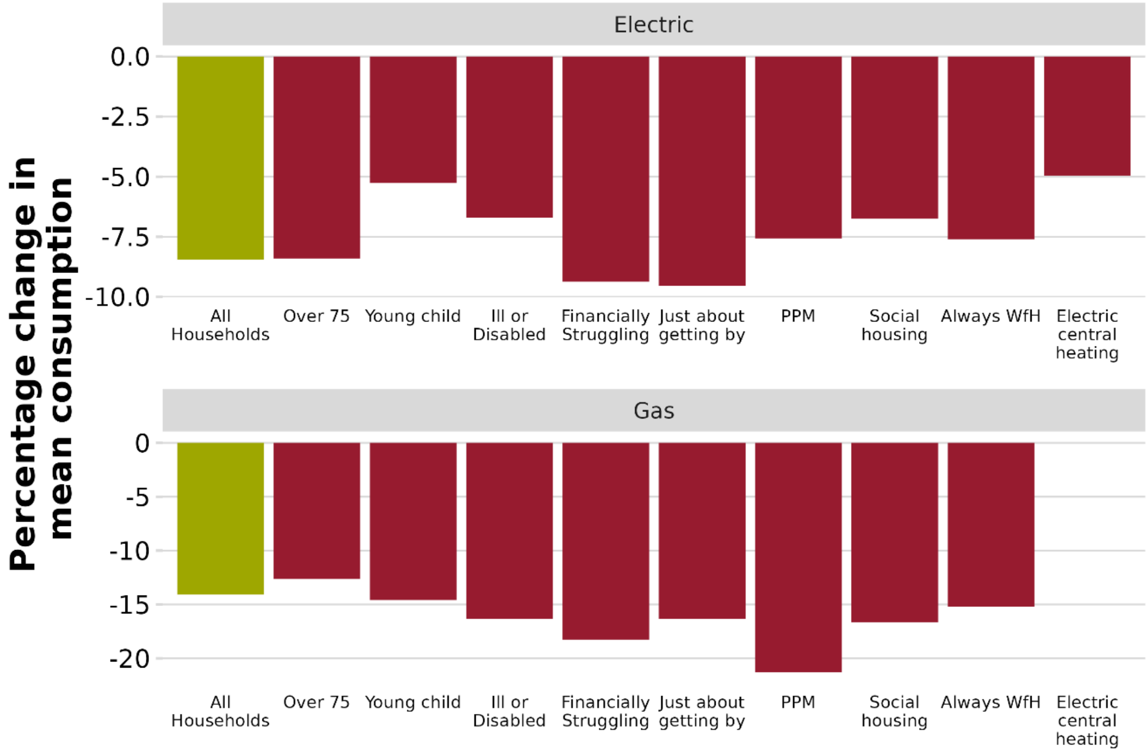
Hypothesis	Conclusion
There are some household groups who take fewer actions than other household groups. For example these might include households with young children; those with long term sickness, health or disability issues; and households containing elderly members.	**Mixed impact**. The picture is mixed across household groups and across gas and electricity consumption, as described in Table 6.
Households in financial difficulty may not be able to take many additional actions compared with previous years.	**No**. The household groups that appear to take the most actions are those in financial difficulty, as described in Table 6.
The impact of any given action will not vary depending on the characteristics of customers living in that household but will depend more on the characteristics of the dwelling. However, housing types may be correlated with household demographics	**Yes**. The impact of all actions appear to have the same effect on consumption, as described in Section 4.4.2.

Source: Frontier Economics

4.2 Impact on household consumption

In Section 3.1 we find that households reduced consumption on average for both gas and electricity. However we find some variation in consumption across household groups as shown in Figure 20. This shows the percentage difference in mean consumption for each household group.

Figure 20 Electricity and gas consumption change across household groups



Source: Frontier Economics analysis of SERL data
Note: Note that the scales between the electricity and gas charts.

One of our findings in Section 3 is that the change in gas consumption is greater than the change in electricity consumption and we find that this holds across all household groups. One of our hypotheses was that we expect some household groups to reduce energy expenditure the less than others, specifically the ill and disabled, the elderly and households with young children. We have mixed findings:

- For electricity consumption, this is true for households containing young children or ill and disabled people. For households with elderly members there is a similar percentage decrease in electricity to the average household.
- For gas consumption, these groups show similar to average declines in consumption, however elderly households tend to make smaller reductions than the whole sample.

For the elderly, this may have been a result of the additional financial support they received, particularly the Winter Fuel Payment, which is available to all over the eligible age, as well as targeted payments to those eligible for other schemes such as the Warm Homes Discount scheme and the Cost-of-Living Payment.[65]

[65] UK Government, Help with your energy bills, https://www.gov.uk/get-help-energy-bills

Households that describe themselves as always working from home tend to have higher electricity and gas consumption than the average household. In terms of changes in consumption, changes in gas consumption are slightly larger than average while changes in electricity consumption are slightly smaller than average. This might be because they were previously using more heating than average but are now reverting to more typical levels.[66] Or it could be a sign of more compensatory actions. While there is no definitive evidence on whether these households are continuing to work from home, they are maintaining their electricity consumption slightly more than other households. That suggests they might be continuing to work from home throughout the cost-of-living crisis. However these households are not heating homes as much as they were. If this is true, it suggests that working from home behaviour identified in our previous VENICE report is likely to persist for a longer time period.

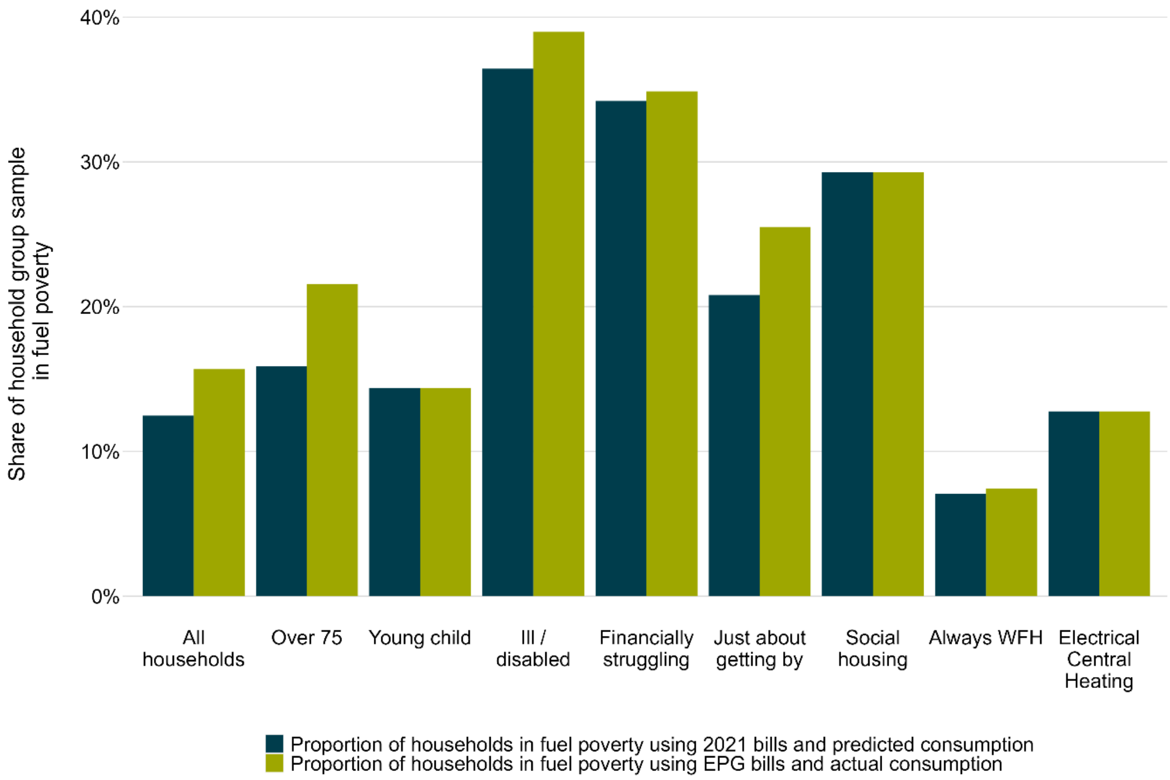
Households that are 'financially struggling' or 'just about getting by' typically have comparatively larger decreases in energy consumption, while households with prepayment meters have the largest decreases in gas consumption. This is a troubling finding: households who are 'financially struggling' are more likely to have lower consumption than other households, suggesting they may already underheat their homes. For these households to be reducing consumption more than average, there is a risk they would be cold over the course of the winter while those households with prepayment meters may be engaging in harmful self-disconnection.[67]

In Section 3.1 we illustrated the estimated impact of bill increases on fuel poverty across all households in the sample. In Figure 21 we show the estimated proportion of households in fuel poverty before and during the cost-of-living crisis (based on 2021 bills and estimated 2022 bills).

66 Average actual consumption for households that always work from home is very similar to predicted consumption for all households.

67 This may have been exacerbated by the fact that a quarter of the Energy Bills Support Scheme vouchers issued for households on prepayment meters had not been redeemed as of February 2023, according to a report by the Public Accounts Committee. the PAC raised concern over the lack of urgency and calls for an update on plans to ensure affordable energy for this winter.

Figure 21 Estimated proportion of each household group in fuel poverty using predicted and actual bills



Source: *Frontier Economics analysis of SERL data*

Note: *The blue bar shows the fuel poverty level using 'predicted bills', which refers to bills calculated using predicted or counterfactual consumption and where we assume tariffs are at the price cap. The green bar shows the fuel poverty level using 'actual bills', which refers to bills calculated using smart-meter consumption data and energy prices as set out by the Energy Price Guarantee. However, this is still an estimation as we have not deducted support schemes such as the Energy Bills Support Scheme (see Section 2.1).*

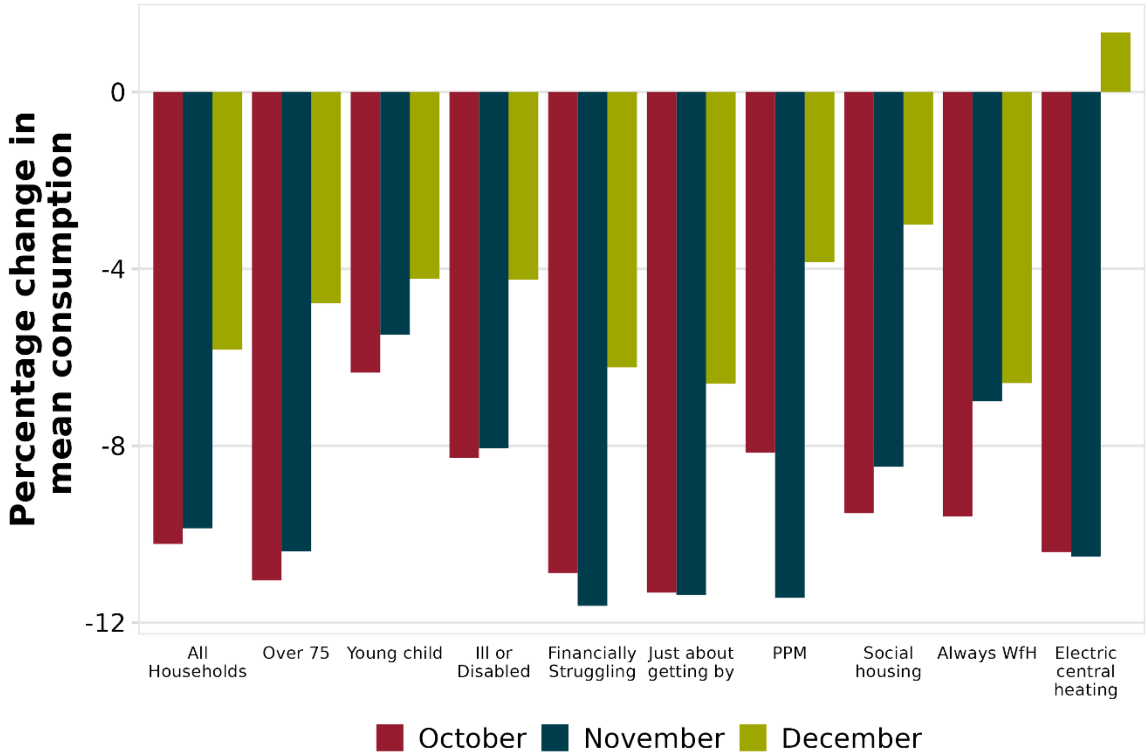
We can see that almost all household groups have increases in the number of households in fuel poverty, but with variations across household groups. For example, households that are 'financially struggling' and households with ill and disabled people typically have higher levels of fuel poverty. These households are already struggling to heat their home and we find that these households, particularly those who are 'financially struggling', are typically reducing consumption more than other households. A priority for NGED and other DNOs should be to identify those households and ensure they are able to heat their homes effectively.

We can also identify the household groups that had the biggest increases in fuel poverty. Households with elderly customers saw the biggest increase as over 35% more households fell into fuel poverty. These households typically reduced gas consumption less than other households, which suggests these households are prioritising heating consumption over other spending. Households 'just about getting by' also saw large increases in the proportion in fuel poverty, but these households also cut back on consumption more than the average household. This suggests there might be significant numbers of customers on the edge of fuel poverty and therefore in more need for help from stakeholders with a responsibility to assist such customers.

4.3 Changes in consumption over time by household group

The previous section considers how energy consumption changes across household groups. As per Section 3.2 we consider how this changes over time for household groups. Figure 22 and Figure 23 illustrate this. There are a number of interesting conclusions to draw from these charts.

Figure 22 Percentage change in electricity consumption across October to December 2022 for all household groups



Source: Frontier Economics analysis of SERL data

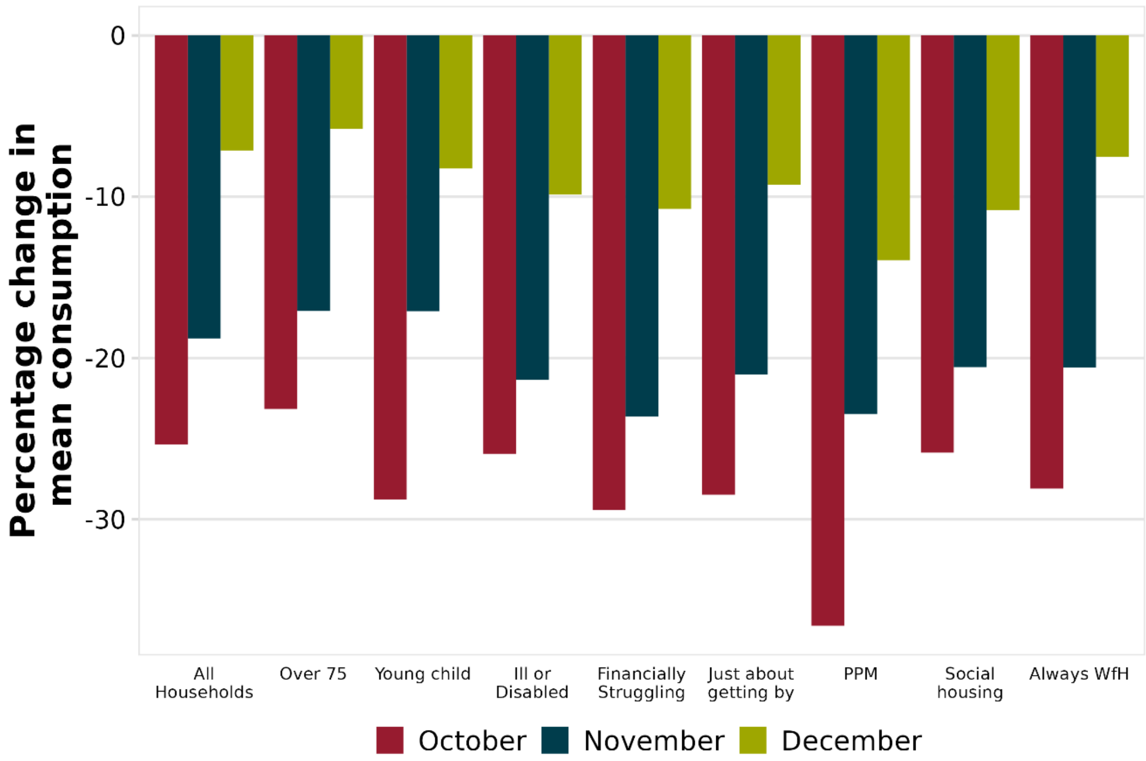
On changes in electricity consumption:

- The trend we saw in Section 3 where households start with a large percentage reduction in consumption in October and November but a small reduction in December is shown by most household types. The exception is those households that work from home which saw less variation between months, with most of the reduced response (in percentage terms) happening between October and November.
- ‘Financially struggling’ households and households ‘just about getting by’ tend to have higher changes in consumption in October and November but revert towards predicted

consumption in December. This is a similar pattern to the elderly, who bounce back towards predicted consumption even more in December.

- Customers with electric central heating have similar changes in consumption to all households in October and November but consume more electricity in December. This is likely due to heating demand in December increasing, particularly as it gets colder.

Figure 23 Percentage change in gas consumption across October to December 2022 for all household groups



Source: Frontier Economics analysis of SERL data

On the changes in gas consumption:

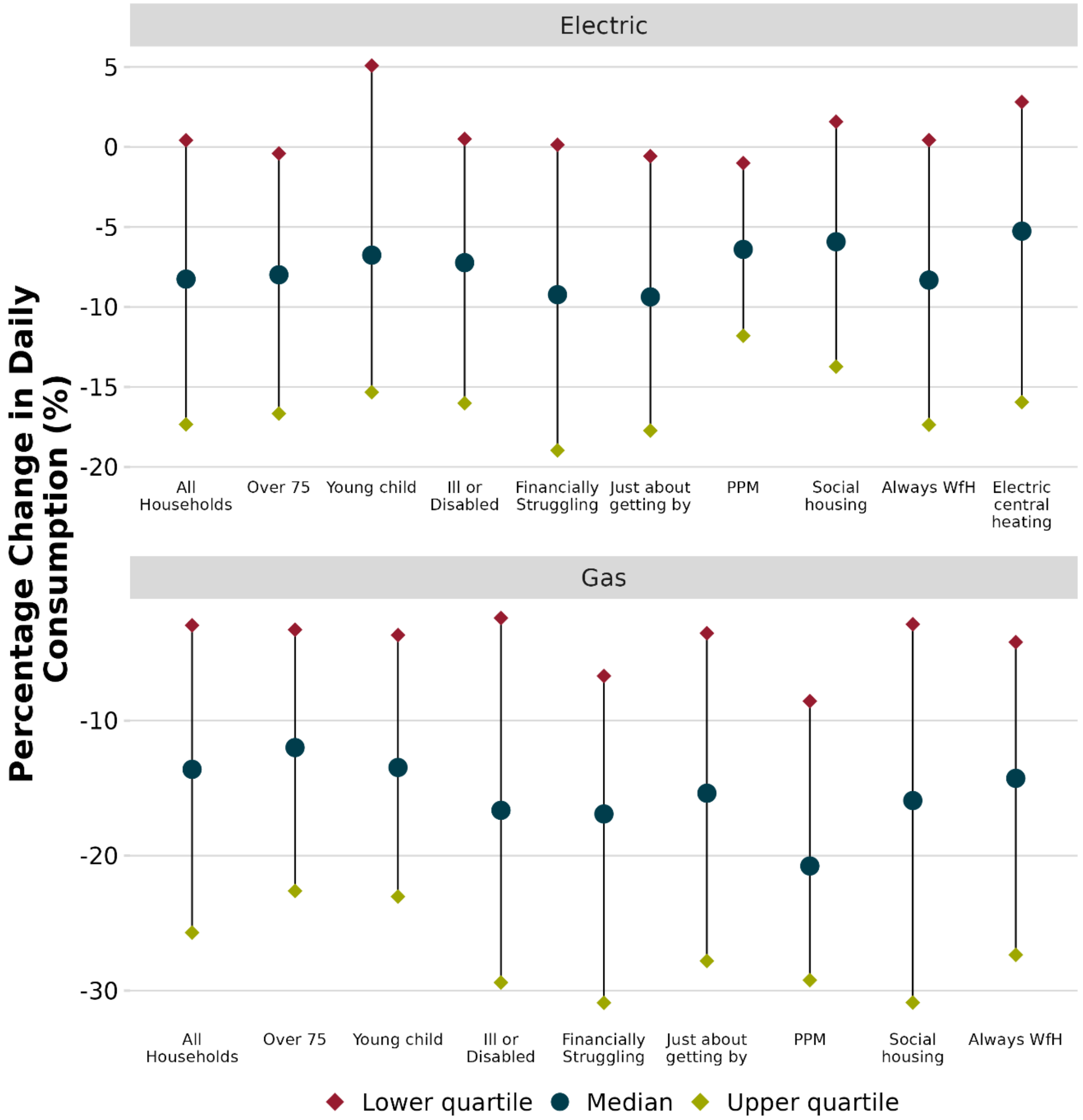
- All households tend to demonstrate the same pattern over time as the average. The largest percentage change happened in October, with a slightly smaller change in November and much smaller change in December.

- Pre-payment meter households showed the largest variation in consumption changes over time. In October they were reducing consumption by almost 40% but by December their reduction in consumption was less than 15%.

- Many of the remaining household groups show similar changes in consumption over time compared with all households.

Figure 24 shows how the changes in consumption varied across different household groups.

Figure 24 Distribution of consumption changes across all households for October to December 2022



Source: Frontier Economics analysis of SERL data

We find that:

- Compared with other groups, households with elderly people behaved more homogenously and had the lowest median change in gas consumption. However we still observe substantial changes in consumption for a large proportion of that group (around a quarter of this group reduced gas consumption by 20% or more).
- Households that are 'financially struggling' have a large proportion of households who decrease consumption across the winter by more than 30%. Similarly the ill and disabled

household group appears to have at least a quarter of households reducing gas consumption by more than 30%. Both these groups include customers in vulnerable situations who are reducing gas consumption by a substantial amount. The result of this is likely to be significant under-heating of homes.

Given this large variation within our household groups on metrics of vulnerability, there may be other characteristics which are associated with changes in consumption that we are unable to observe (or at least are not associated with the metrics of vulnerability we have used).

Part of the response variation may be dictated by eligibility for financial support from the government. Many households in these groups could be eligible for hundreds of pounds off their energy bills, depending on their specific situation. The extent to which they face discounts could influence their approach to spending on energy, which may help explain the variation within and across groups. Another reason could be to do with housing stock and the relative levels of energy efficiency. Owner occupied households and privately rented properties tend to be less energy efficient than those in social housing.[68]

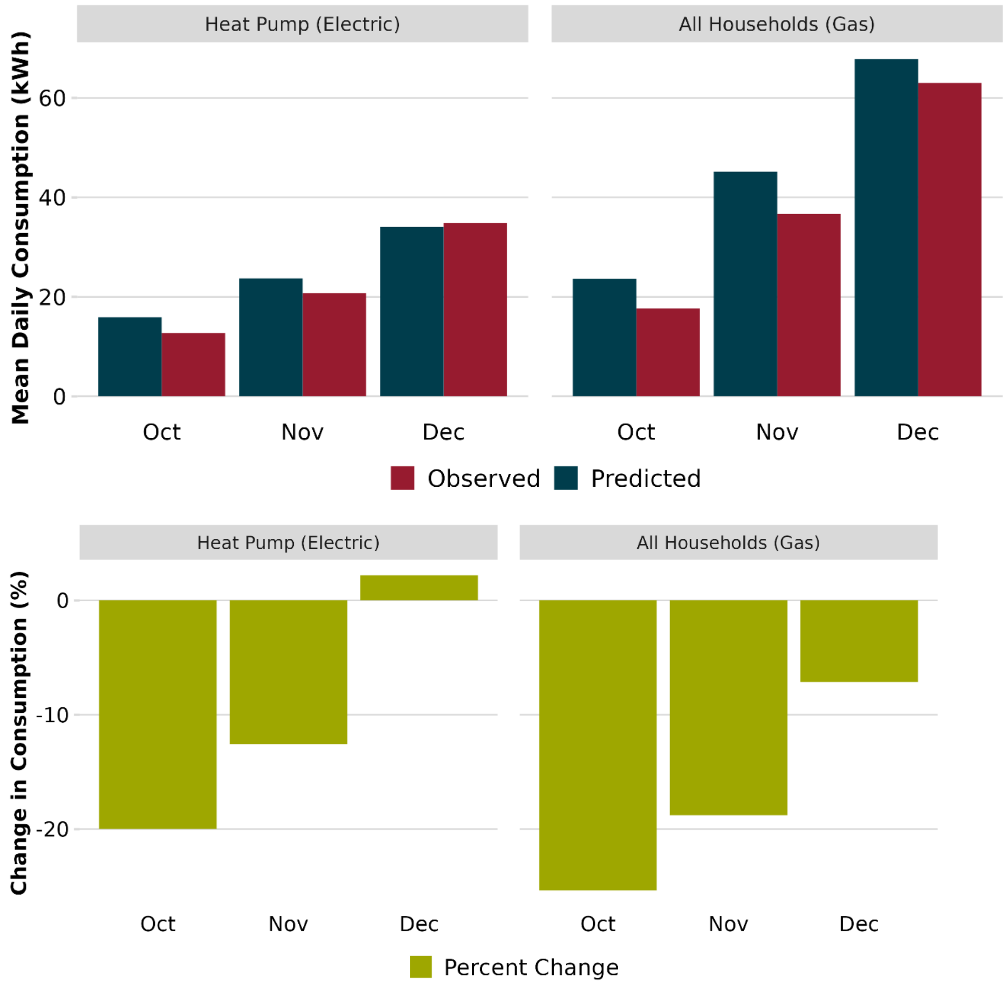
4.3.1 Electricity consumption changes for households with heat pumps

We also want to consider the behaviour of households with heat pumps separately. These households can give NGED an insight into how households might respond to similar events in the future, when domestic heating is expected to be predominately electrified. We compare the observed and predicted electricity consumption for heat pump customers against other households' electricity consumption in Figure 25 and Figure 26.[69] In this sample we are able to identify 46 households with heat pumps with the required data to do this analysis.

68 Figure 3.15, Annual Fuel Poverty Statistics in England, 2023, Department for Energy Security and Net Zero

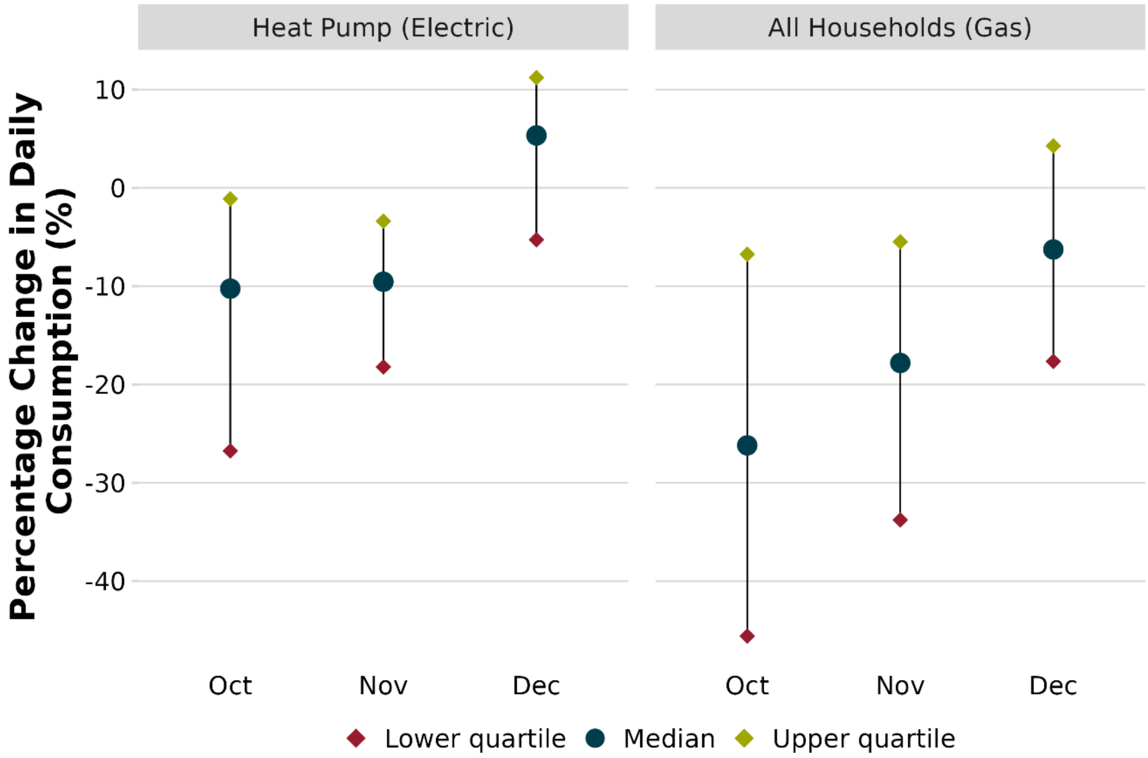
69 We do not normalise electricity consumption since their consumption patterns are inherently atypical.

Figure 25 Mean daily electricity consumption change for households with heat pumps compared with change in gas consumption for all gas consuming households



Source: Frontier Economics analysis of SERL data

Figure 26 Range of daily electricity consumption change for households with heat pumps compared with change in gas consumption for all gas consuming households



Source: Frontier Economics analysis of SERL data

We find that there is a strong seasonal shift in consumption for households with heat pumps that mirrors gas consumption across all households (as per Figure 25), although heat pump customers tend to change their consumption less than gas customers. This could be for a number of reasons.

First, heat pumps tend to be associated with higher income households. These households may have been less affected by the cost-of-living crisis and have less financial pressure to reduce consumption[70]. Second, there may be fewer actions to take with a heat pump to temporarily reduce consumption or optimise energy performance (other than switching it off completely), which we find in Table 6. It can also be seen that some households make no changes to consumption over the whole period, while other households make significant changes in October and November but revert towards predicted consumption in December.

70 30% of households within the overall sample have gross annual household income above £50,000, compared to 38% for households that only have heat pumps as their form of heating.

4.4 Actions taken by household group

4.4.1 Description of actions taken by household groups

Given that consumption varied across household groups, we want to understand whether household groups that reduced consumption took more actions. And if so, we want to understand which actions these household groups take more of. We can analyse the survey responses to do this.

In Table 6 below, we consider whether different household groups are more or less likely to take an action compared to the overall sample. For example, 59% of the sample ‘heat the home for fewer hours’ and a value of ‘20’ for the ‘financially struggling’ household group for the same action means that 79% of households in this group take the action – a difference of 20 percentage points. Household groups which take an action less than the sample are highlighted in red, whilst household groups which take an action more than the sample are highlighted in green. Actions which are statistically significant are highlighted in bold.[71]

[71] In simple terms, statistical significance means that a result is unlikely to be only explained by randomness or chance.

Table 6 Difference between proportion of actions taken by household groups and all respondents (households taking actions more in green; households taking actions less in red; statistically significant actions in bold)

Action	Whole sample	Over 75s	Young child	Ill / disabled	Financ. struggle.	Just about getting by	Pre-payment meter	Social housing	Always WFH	Electric central heating	Heat pump
Wear more clothes than turn heating on or up	68	-2	1	4	**10**	**8**	8	0	2	**-9**	-17
Heat home for fewer hours	59	**-7**	0	5	**20**	**14**	16	6	3	**-12**	-26
Turn thermostat down when home	59	-3	2	5	7	**5**	2	3	1	-6	-10
Turn thermostat down / heating off when away	49	-2	0	8	**18**	**8**	12	8	-1	**-14**	-21
Reduce boiler flow temperature	42	0	-2	4	**11**	**10**	5	2	1	**-16**	NA
Turn radiators down when rooms aren't used	41	0	-3	5	**15**	**5**	13	9	-1	-7	-17
Use electric blanket or hot water bottle	41	-3	0	8	**17**	**11**	8	11	2	-7	NA
Use standalone heater than turn heating on or up	33	-1	8	8	**16**	**7**	13	2	1	5	-9
Close curtains / blinds at night	31	**4**	-4	3	**18**	**6**	13	11	-6	-5	-15
Turn radiators down when rooms are used	30	0	-4	9	**17**	**8**	16	12	-1	-3	NA
Turn lights off in unused rooms	52	**4**	-2	9	**16**	**8**	6	5	-1	-6	-10
Avoid using the cooker or oven	38	-1	-1	4	**13**	**10**	0	4	-1	-1	0
Turn appliances off standby when not in use	36	1	1	9	**21**	**10**	9	**13**	-1	-4	-8
Take short showers rather than longer showers	34	2	3	9	**25**	**11**	19	13	-1	3	2
Dry clothes without using a tumble dryer	32	**3**	2	7	**18**	**9**	12	7	1	-1	-3
Only use washing machine with a full load	33	2	-4	16	**19**	**11**	22	**17**	**-9**	-5	-10
Use washing machine at 30 degrees or lower	34	2	-2	10	**17**	**8**	12	11	-5	0	-6
Take a shower rather than having a bath	24	**5**	2	9	**24**	**10**	24	**16**	-5	1	NA
Use the dishwasher rather than washing up	15	2	0	9	**15**	**6**	NA	11	3	-3	NA

Source: Frontier Economics analysis of SERL data; Actions which reduce heating demand are shown in the top half of the table, whilst actions which reduce non-heating demand are shown in the bottom half of the table

Table 6 shows that household groups which take more effective actions are the ones that reduce consumption by a greater amount. 'Heating the home for fewer hours' is one of the most effective actions for reducing electricity and gas consumption (as shown in Table 2 and Table 3) and the household groups 'financially struggling', 'just about getting by', households in social housing and households with pre-payment meters carry out this action considerably more than the overall sample. As shown in Figure 20, these household groups have bigger decreases in gas consumption than the overall sample. This also holds true for households that are 'financially struggling' or 'just about getting by' with respect to electricity consumption. In addition, these four household groups carry out the actions 'use electric blanket or hot water bottle than turn heating on or up', which is one of the most effective actions (as shown in Table 3), more than the overall sample by a considerable margin. This is not surprising as these households are also more likely to take heating reducing actions (such as 'heating the home for fewer hours' and 'turn radiators down when rooms are used').

Our hypothesis was the households who are more financially vulnerable may have been less able to take additional actions this winter given those were the households that were likely to have already been taking actions to save on energy consumption. However we find that these households have had to find additional ways to reduce the impact of the crisis by taking even more actions. Households who describe themselves as 'just about getting by' also take significantly more actions than the rest of the population. This just shows what a difficult situation these customers have been put in: facing significant price rises and no additional income there are few alternatives to using less energy and those choices involve other unpalatable actions such as cutting back on other essentials (such as food) or running up a debt.

This analysis does suggest that these households are more likely than other households to mitigate their reduced gas consumption with compensatory actions, such as using an electric blanket, hot water bottle or standalone heater than turn heating on or up. This suggests these households are likely to be more aware of actions that will help minimise their bill impact. However these households are still the most likely to be underheating their homes.

In the previous section, households always working from home appear to be changing their gas consumption more than average and their electricity consumption less than average. This is reflected in these households taking compensatory actions slightly more than the average household. This suggests households always working from home are not necessarily changing their working patterns but modifying their energy consumption behaviour. However these results are not statistically significant, so it is difficult to draw firm conclusions from this.

Our other hypothesis was that there are some household groups that may be less financially vulnerable but more reliant on energy such as households with young children, households with ill or disabled members and households with elderly people. We thought these households would be less likely than other vulnerable groups to take energy saving actions as they would prioritise energy usage. The results confirm our hypothesis. Households with elderly members or young children carry out actions in similar proportions to the overall sample. Whilst households with ill or disabled members carry out actions slightly more than the overall sample, these results are not statistically significant.

We have also analysed the extent to which different household groups take sets of actions, namely:

- any action (compensatory or energy-saving);
- any action to reduce heating demand; and
- any action to reduce non-heating demand.

'Financially struggling' and 'just about getting by' households are more likely to take these three sets of actions than the overall sample of households. This is consistent with these household groups being likely to take single actions (see Table 6 and showing large changes in electricity and gas consumption (see Figure 22 and Figure 23). Households containing an elderly member are less likely to take any action to reduce heating demand and this is consistent with Figure 23, which shows that these households have smaller changes in gas consumption than the overall sample of households.

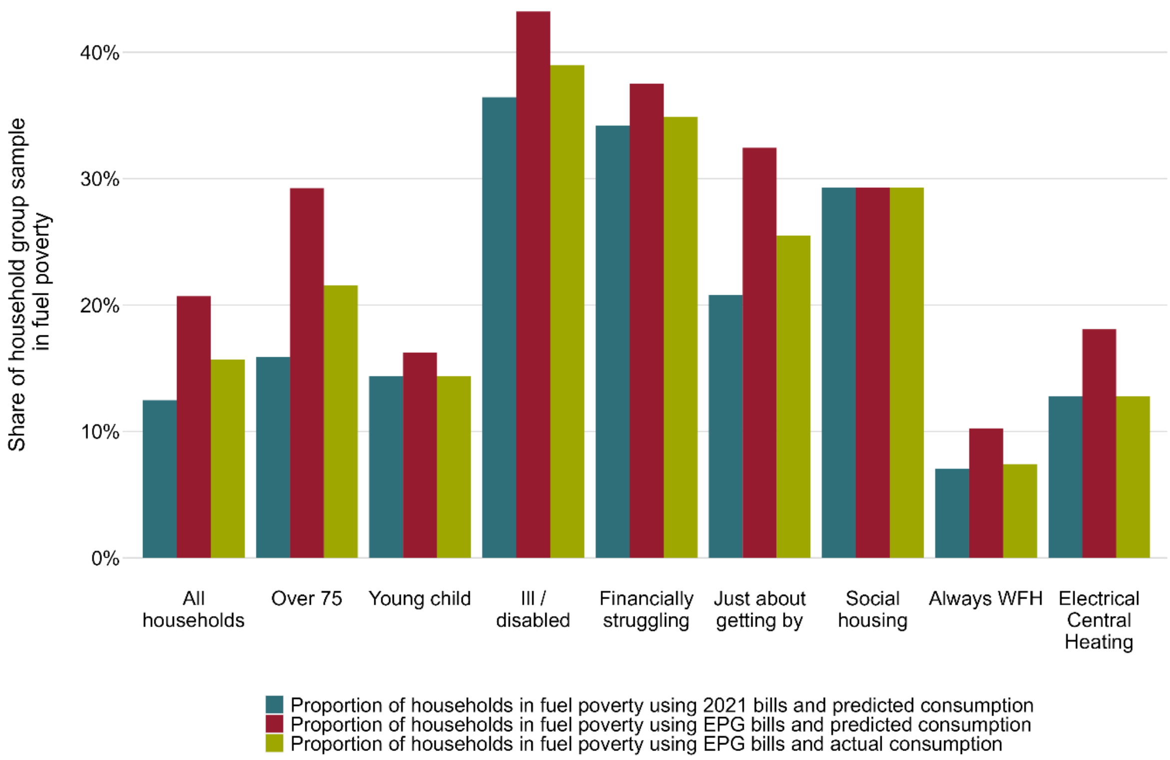
4.4.2 Impact of actions on household groups

We next consider the impact of actions on consumption by household group to understand whether actions for particular household groups have different impacts on consumption than the average impact. Our hypothesis was that the impact of any given action will not vary depending on the characteristics of customers living in that households but will depend more on the characteristics of the dwelling (while recognising that housing types may be correlated with household demographics).

We find that none of the actions taken by household groups have a significantly different impact on their consumption suggesting that the impacts of actions do not vary by household groups. This means that the impact of taking an action is likely to be similar for a household in a vulnerable situation and an average household. Full results of this analysis are available in Annex D .

We can also identify the impact of actions on households entering fuel poverty, similar to our analysis in Section 3.3.3. This is shown in Figure 27 below.

Figure 27 Estimated proportion of each household group in fuel poverty using predicted, counterfactual and actual bills



Source: Frontier Economics analysis of SERL data

Note: The blue bar shows the fuel poverty level using 'predicted bills', which refers to bills calculated using predicted or counterfactual consumption and where we assume tariffs are at the price cap. The red bar shows the fuel poverty level using 'counterfactual bills', which is the same calculation as the blue bar except that we now calculate bills using energy prices as set out by the Energy Price Guarantee. The green bar shows the fuel poverty level using 'actual bills', which is the same calculation as the blue bar except that we now calculate bills using smart-meter consumption data. However, this is still an estimation as we have not deducted the value of support schemes such as the Energy Bills Support Scheme (see Section 2.1).

The impact of changes in consumption on fuel poverty vary across household groups. There are some household groups where the estimated change in fuel poverty is small. For households, such as those in social housing, this is because a large proportion have an EPC rating that would mean they are not classified as in fuel poverty whether they change consumption or not.

However there are many household groups where the reduction in fuel poverty as a result of changes in consumption is large. For example, the proportion of elderly households in fuel poverty moves from 29% to 22% as a result of changing their consumption. This is large compared with 'financially struggling' households, where the proportion in fuel poverty moves from 38% to 35% as a result of changing their consumption. However we find that elderly households are less likely to take actions than 'financially struggling' households (see Table 6) and reduce consumption less on average (see Figure 20). This result is likely due to a number of factors.

First, ‘financially struggling’ households may be more likely to have better EPC ratings (which makes them less likely to fall into fuel poverty). Second, elderly households may have less housing costs than we estimate, which potentially underestimates disposable income after housing costs and hence makes elderly households more likely to be in fuel poverty. Finally it might be that the average elderly household does not take more actions than average. But it might be that elderly households on the edge of fuel poverty (i.e. with low incomes) are more likely to make changes to their consumption to avoid fuel poverty

However there are some caveats to this analysis. We do not consider changes in income or EPC ratings over time. In our analysis income is estimated based on a range from our survey, while EPC ratings are based on information from a snapshot when the household joined the sample. We also are unable to means-test all the energy price related support schemes, so we do not apply these to households in our sample.

4.5 Conclusion

There are a number of important conclusions that we can draw from this analysis.

It is those households who are ‘financially struggling’ or on prepayment meters that have reduced their consumption most. This is a potentially troubling finding: households who are ‘financially struggling’ may already have been underheating their homes while those households with prepayment meters may be engaging in harmful self-disconnection or self-rationing. There is also a higher-than-average decrease in gas usage for ill and disabled households, another group who may be particularly vulnerable in the face of high energy costs. In contrast, elderly households cut back on gas use less than average. This could reflect the fact that they are directing the extra winter fuel payments they get to maintaining their comfort levels, or that they are prioritising the need to stay warm by making compromises elsewhere.

Almost all household groups have seen increases in the number of households in fuel poverty. For example, households that are ‘financially struggling’ and households with ill and disabled occupants typically have higher levels of fuel poverty. This is despite them making greater than average reductions in energy usage. Households with elderly customers saw the biggest increase as over 35% more households fell into fuel poverty, reflecting the fact that they are more likely to have made smaller reductions in consumption than average.

The trend we saw in Section 3 where households start with a large percentage reduction in consumption in October and November but a small reduction in December is shown by most household types. An exception is those households that work from home who saw the largest reduction in their electricity response in November. Customers with electric central heating have similar changes in consumption to all households in October and November but consume more electricity in December. This is likely due to heating demand in December reverting to predicted levels, particularly as it gets colder.

Households that are ‘financially struggling’ and those that are ill and disabled have at least a quarter of households reducing gas consumption by more than 30%. Both these groups include customers in vulnerable situations who are reducing gas consumption by a substantial amount. The result of this is likely to be significant under-heating of homes. Compared with other groups, households with elderly people behaved more homogenously and had the lowest median change in gas consumption. However we still observe substantial changes in consumption for a large proportion of that group (around a quarter of this group reduced gas consumption by 20% or more).

Households who are ‘financially struggling’, just about getting by, in social housing or have pre-payment meters carry out more actions to reduce their consumption than other groups. Heating the home for fewer hours is an action that they undertake considerably more than the overall sample and this is a big driver of the reduction in consumption that they achieve. They also take more compensatory actions than other groups (such as use electric blanket or hot water bottle). While these actions deliver them a greater than average decrease in gas consumption than the overall sample, it is to be hoped that the compensatory actions mitigate the loss of comfort to some extent.

Households with heat pumps are less able to take incremental actions to reduce their consumption. Households with heat pumps have lower change in consumption compared to changes in gas consumption. This might be because they are, on average, higher income households. It also might be because these households may have fewer actions they can take to reduce heating consumption (for example, it might be more difficult to incrementally turn up or down the heating on a heat pump. This is reflected in analysis showing heat pump households are statistically less likely to take actions compared with all other households.

5 Implications for NGED and DNOs

Section 3 and Section 4 focused on the impact of the cost-of-living crisis on consumption and household bills. We summarised our key findings in Sections 3.4 and 4.5.

In this section, we draw out the implications of these findings for NGED and other DNOs. We consider the implications for electricity networks, which means focusing on electricity demand. However the future electrification of heat means we also need to take into account how heating demand changed in response to price increases and what DNOs can learn from this: Given the majority of households changed their heating consumption in response to price increases, it is important for DNOs to consider the implications with increased heat pump usage and how households might respond to prices.

We consider the implications in two areas:

- **Network planning**. Households' reactions to periods of high prices may have implications for demand forecasting and for estimating access to flexibility, both of which are important to DNOs.
- **Customer vulnerability**. DNOs have obligations towards customers in vulnerable circumstances. The findings of this report have implications for both how these customers can be identified and the way in which they can be supported.

5.1 Impact on network planning

We consider two aspects of network planning. First are network forecasts of local area demand. DNOs produce these as part of their DFES processes to identify which parts of the network may become constrained and require reinforcement or flexibility. Second is flexibility, which refers to the ability for consumption to reduce temporarily to allow the system to balance. If there is a need for flexibility, DNOs need to understand where flexibility can come from and how much flexibility could be provided.

5.1.1 Network forecasts

Short-to-medium term (e.g. next 5 years)

We have seen in Section 3 that demand for electricity this winter was reduced due to customer actions. Given our analysis only goes to the end of the year, additional analysis of the full winter would need to be made before it is clear whether the reduction in impact seen towards the end of December continued throughout the winter. It will be important to understand this in interpreting the use of winter 2022/23 profiles in any future calculations.

We also note that we have not assessed the impact on peak demand as part of this analysis, which is the more important measure for determining future network requirements. However since many of the actions discussed in this report typically have a large impact during peak demand periods, we might expect that the impact on total demand and peak demand are similar.

DNOs might want to particularly consider the impact for parts of the electricity network that are off the gas grid and use electric heating. The impact of the cost-of-living crisis on electricity consumption could be much greater for households in these areas, since they rely on electricity for heating. Similarly Section 3 and Section 4 both showed how the impact of the cost-of-living crisis varied by household group. It is possible that demand will have been particularly depressed in certain areas where there are clusters of particular household types.

When forecasting demand for winter 2023/24 it will be important to consider these findings alongside the wider context. On one hand, the reduction in consumption this winter might be seen as a temporary reduction in response to high prices. However we have not observed how these reductions played out over the course of the whole winter, so we are unable to draw firm conclusions. The likelihood of the price impact continuing into next winter depends on the evolution of energy prices as well as net household incomes moving forward (accounting for increases in mortgage rates and other household costs). This will require ongoing monitoring and may require looking at parts of the network that may be particularly affected given the demographics. For example, areas with more 'financially struggling' households may see larger decreases in consumption if the challenging economic conditions continue through next winter. Areas with more electric heating may also require further monitoring.

To put this in context, NGED's network planning process involves the use of load forecasts at two main points. First, DFES forecasts of load growth are applied to measured demand profiles and used to determine those areas of the network where reinforcement may be required. Second, where a possible need for reinforcement has been identified, the load forecasts allow an appropriate reinforcement solution to be designed and assessed against the use of flexibility.

If the measured demand profiles used as the basis of these forecasts have been affected by the cost of living crisis, and if this impact is temporary (and so peak demand will rebound), then there is a risk that this process could underestimate how quickly certain areas will require reinforcement. This would particularly affect areas where electricity consumption has been especially impacted by the cost of living crisis (for example, areas with large numbers of electrically heated properties, with concentrations of groups like financially struggling customers who may had reduced their demand the most). Although, given the relatively small impact of the cost of living crisis on electricity consumption, it is not clear whether this impact would be significant.

When considering these factors in the round, DNOs may want to have a conservative approach to forecasting. This is because it is peak demand that matters most to DNOs, which means DNOs need to plan for the maximum demand level rather than average demand. There is also a risk that reductions in consumption observed this year might mask underlying trends which could increase peak demand in the future. Equally, this could be the start of a longer-term trend towards customers adapting to a future of higher ongoing energy costs, potentially alongside squeezed incomes. It will be important for DNOs to continue to monitor these developments and the impact on consumption.

Longer term

Since DFES is used by all DNOs to plan the long-run development of the distribution network, particular attention should be paid to heating behaviour. This is because a large proportion of heat demand will move to electricity as the energy source.

DNOs will therefore need to continually consider how heating behaviour evolves over a longer period. In the context of network build, they will also need to consider the impact of heating demand on peak demand as heat pumps become more prevalent. Specifically NGED's DFES does not consider how behaviours might change over time but note that smart meter data should be used to monitor this behaviour change and "incorporated into the profiles".[72] It is worth DNOs considering whether demand profiles based on previous winters are still valid and whether lower consumption by certain demographics might persist into the future. Understanding what happened in the second half of the winter would help draw more conclusions into that persistence.

Our analysis into heat pump households suggests they exhibit similar behaviour to households with gas boilers. However it is important to note the key differences. For example households with heat pumps do not reduce their consumption as much as households with gas boilers. This might be because fewer actions to reduce consumption are available to heat pump households. But it might be because heat pump households have higher incomes (and therefore may be affected to a lesser extent by the cost-of-living crisis). It is worth NGED monitoring changes in heat pump behaviour for their planning scenarios, particularly as different demographics adopt heat pumps.

This is particularly important as the energy transition continues and household bills are affected. To the extent bills remain high as a result of the transition there may be cost of living issues persisting for some customers, particularly as the EPG is phased out over summer 2023. Given NGED's DFES modelling currently applies an overall change in consumption but does not consider differences between household profiles (e.g. whether winter demand may evolve differently for certain types of household), it will be important to explore how households respond to price changes and update heat pump assumptions with different customer profiles and sensitivities.

72 Distribution Future Energy Scenarios, customer behaviour profiles and assumptions report, heat pumps, page 77, National Grid Electricity Distribution, 2022

5.1.2 Flexibility

Household willingness to reduce electricity consumption

It is increasingly important for NGED to understand how households can flexibly use energy in response to external shocks. It is possible that the GB energy system may face supply shortages in future, for example in a cold winter with a long periods of lower wind output.

It will become increasingly important for system participants, including network companies, to plan for these events. One of the ways they could do this is to understand where flexibility exists on the grid and deploy that flexibility where appropriate.

In general this requirement for flexibility may only be needed for short periods (e.g. turning off the heat pump during the peak on some winter days). While the analysis we have undertaken for this study does not consider the likelihood of customers agreeing to this, it does show an ability for consumers to take actions that materially affect their energy consumption over a longer period (i.e. over a number of days, weeks and months). In the future, as consumption returns to more typical levels and uptake is higher, system costs might be reduced if demand could be reduced in this way. For example if there is a period in winter with lower wind output than anticipated, DSOs can help manage local supply and demand balances which would in turn help national balancing. However this depends on the extent to which households with heat pumps can take equivalent energy-saving actions to gas boilers today. The availability of such temporary flexibility may also be reduced in the event of a future shock to bills if this means that customers are already lowering consumption and unable to reduce their usage further.

While we are not able to draw conclusions from this analysis about consumer flexibility in short periods, we do observe that households will change their heating behaviour in response to price signals, often at a cost to their own comfort. However there are some caveats to note. Households with heat pumps took fewer actions to reduce energy consumption than all other households. It is not clear whether this is because, from a technical perspective, there are fewer available incremental actions for heat pump households to take to reduce consumption (other than switching it off). Or it could be because these households are less price sensitive. It is also notable that when it became colder, households' consumption reverted to more normal levels. We are not sure whether this persisted as the data set we had access to for this work only ran to the end of 2022.

In order to gather more evidence around the scope for flexibility, this should be built into heat pump trials. For example DNOs could offer a financial incentive to households to temporarily switch off their heating which may result in some level of temporary discomfort. This could be tested with households being called in a realistic pattern over winter, including on particularly cold days. The idea would be for DNOs to measure how households respond. Similar innovation trials have been done to analyse the future of heat pump flexibility, such as the *EQUINOX* project by NGED or the *Energywise Energy Shifting Trial* by UKPN.[73] [74]

Households increasing electricity consumption

Given the actions and the impacts on consumption discussed in Section 3.3 we can already identify the scale in which households took actions. One finding (see Figure 30) is that over a quarter of households used standalone electric heaters. Results in Table 2 and Table 3 suggest that increased usage of standalone electric heaters is associated with reduced gas consumption, suggesting that some households are substituting central heating use for individual electric heaters.

Overall we found that the net impact on electricity consumption was negative for most households. However it is possible that increased usage of standalone electric heaters had an impact on daily load profiles, perhaps even increasing peak demand if they were all turned on at once. Therefore DNOs may wish to look at daily load profile data to understand whether increased use of standalone heaters had an impact on peak demand. If so, they may want to consider including this effect in load forecasts to ensure future peak demand can be met. Future research might involve looking specifically at on-gas-grid areas with households that are lower income or financially struggling, where households are more likely to take action to use a standalone heat (see Table 6), and assess whether peak demand ever increased in this area over the course of the winter.

5.2 Impact on customers in vulnerable situations – fuel poverty

We now consider the implications of our analysis given the DNOs' responsibilities for customers in vulnerable situations. We focus on NGED's own vulnerable customer strategy and responsibilities. Other DNOs may have their own considerations based on their own individual strategies.

NGED has a *Customer Vulnerability Strategy* which considers how it will help customers in vulnerable situations over the five years of the RIIO ED-2 price control.[75] NGED helps those in fuel poverty in two broad ways.

- There are plans to help around 113,000 customers to save a total of £60 million. The aim is to "*develop and implement new interventions for fuel poverty outreach schemes,*

[73] EQUINOX (Equitable Novel Flexibility Exchange), NGED, https://www.nationalgrid.co.uk/projects/equinox-equitable-novel-flexibility-exchange

[74] Energywise, (also known as Vulnerable Customers and Energy Efficiency), SDRC 9.5 Report, The Energy Shifting Trial Report, UKPN, 2018

[75] Western Power Distribution Customer Vulnerability Strategy RIIO-ED2, December 2021, https://yourpowerfuture.nationalgrid.co.uk/downloads-view/41886

specifically targeting advice to support customers in the energy transition and participate in the opportunities this provides to help them with their energy costs".

- There is also the 'Affordable Warmth' scheme which is "*specifically designed to identify and support hard-to-reach customers struggling to heat their homes and meet their energy costs. [NGED] funds outreach targeted in high deprivation areas (revealed by our social indicator mapping). Customers receive fuel poverty support and are assisted to register to the PSR, providing referrals back to [NGED]*".

Below we explain how the results of this analysis may affect how NGED currently identifies households moving into fuel poverty and whether NGED can refine its support to them. We then identify the non-financial impacts on customers and whether NGED can help customers mitigate these impacts.

5.2.1 Identifying households in fuel poverty

NGED's *Affordable Warmth* scheme helps identify households that are in fuel poverty. The challenge for NGED is to ensure the list of households in fuel poverty is continuously updated and captures as many eligible households as possible. As described in Section 3.1 we estimate a 25% increase in the number of people in fuel poverty. For NGED that is a significant number of additional customers to identify and support.

In Section 4.2 we identified the household groups that we estimate as potentially moving into fuel poverty. The household group that appeared to move into fuel poverty to the greatest extent was households with elderly people and people that are 'just about getting by'. This analysis considered the changes in consumption made by households in these groups. While financial wellbeing may not be immediately observable to NGED, whether a household has elderly members is more likely to be observable. While NGED already targets its efforts towards these customers, it might want to consider these customers as increasingly vulnerable as a result of the crisis. Specifically this could mean looking at data from existing outreach activities used to identify households in fuel poverty and confirm whether they are identifying more households in fuel poverty within certain groups (such as the elderly and low income groups). If this is the case, this might mean notifying NGED's "*network of referral partners*" across their license areas, of which there are at least 150 agencies.[76] NGED might want to focus its outreach activities on the groups that are more likely to contain fuel poor households. This might involve working with more referral partners who are specific to those groups.

There may be some households who have avoided falling into fuel poverty by decreasing consumption. However this may lead to underheating of homes, so NGED may also wish to provide support to these groups. The next section discusses the support NGED might be able to offer.

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[76] Western Power Distribution Customer Vulnerability Strategy RIIO-ED2, December 2021, https://yourpowerfuture.nationalgrid.co.uk/downloads-view/41886

5.2.2 Providing effective support to those in fuel poverty

At the moment, NGED's fuel poverty support schemes are provided by external partners. These schemes offer the specific and effective energy-saving advice to fuel poor customers. The analysis in this report offers some evidence for the types of activities that fuel poor customers can do to save the most.

One example of a way customers might be able to save money is by using compensatory actions. For example, if customers turn their heating down or off for longer, they can compensate for this by taking compensatory actions that heat the individual rather than the room (such as an electric blanket). While it might feel counterintuitive for NGED to recommend increasing electricity consumption, this might save customers money across their energy bills. Specifically, NGED might wish to promote the use of hot water bottles, electric blankets and efficient standalone heaters in combination with using their heating less. There has been a history of bad press from energy companies trying to encourage consumers to save money by keeping themselves warm rather than their homes but finding a way to deliver this message effectively, potentially with trusted partner organisations, is important.[77] It is worth considering the organisations within NGED's existing network that would be best placed to deliver these messages, and providing them with evidence (including the analysis from this report) which can be used to justify the effectiveness of these measures.

There is also some evidence that those that used their tumble dryer less, also ended up heating their homes more, potentially to dry their clothes. This increased their bills. Educating customers about the impact of different actions to ensure overall consumption is reduced looks valuable.

There are other actions that can reduce bills without reducing the temperature of occupied properties. However these actions have mixed effectiveness (see Table 3 for more details). We find that only one action of this type is effective at reducing consumption (and therefore bills), which is reducing boiler flow temperature. While low flow temperatures are also more efficient for heat pumps, it would be hoped that heat pumps would be installed in an optimal way, with the flow temperature set as low as possible while still providing adequate heat to the home. However this may not be the case: Given the increasing importance of heat pumps, it would be worthwhile researching whether there are simple actions which can be taken to increase the efficiency of existing installations.

Understanding the potential effectiveness of energy-saving actions will help NGED understand how to help customers in fuel poverty. The learnings above can help specify exactly what actions different households can take to save energy.

[77] https://www.theguardian.com/business/2022/jan/14/eon-says-sorry-for-sending-socks-to-customers-with-advice-to-keep-warm

Overall we find that changing consumption can help a significant proportion of households avoid fuel poverty. This appeared particularly effective for household groups such as elderly households. This is despite, on average, the impact of changes in consumption appearing small in comparison to the changes in price. While the average impact is small, we find that there are some households where taking actions can be the difference between being in fuel poverty or not. It also illustrates how a binary measure of fuel poverty understates the issues facing households: households may only be avoiding fuel poverty by underheating their homes. NGED may wish to carry out further analysis (e.g. surveys) to determine whether the definition it uses of fuel poverty is failing to capture such households.

5.2.3 Non-financial impact on customers

Throughout this report we have tended to focus on the financial impacts of taking energy-saving actions, but there are other important non-financial impacts on customers. The two primary impacts associated with reductions in energy consumption relate to health and comfort. This sub-section describes the impact of each in turn.

A decrease in indoor temperature can contribute to indoor dampness and associated mould. This leads to negative health impacts such as an increase in symptoms of respiratory and cardiovascular conditions, rheumatism, arthritis and allergies.[78] [79] In addition to the direct adverse impact on health, these conditions impose costs on the health service. For instance, BRE estimate that approximately £857 million of NHS treatment bills can be attributed to ‘defects in poor homes which expose residents to excess cold’.[80]

Costs associated with decreased comfort are real but difficult to quantify – they may considerably vary between different types of consumer as perceptions of comfort can vary depending on factors such as age and culture.[81] Discomfort can also drive significant mental health problems.[82]

The implication of this is that there is significant social value associated with warm homes. While reducing consumption might be one way of alleviating the impact of price increases, particularly for fuel poor customers, the non-financial impact remains substantial. We find that households with elderly people are generally more likely to maintain heating consumption.

[78] Barton, A. et al. (2007) “The Watcombe Housing Study: The short-term effect of improving housing conditions on the health of residents” Journal of Epidemiology; Community Health, 61(9), pp. 771–777.

[79] WHO (2008) “Preliminary results of the WHO Frankfurt housing intervention project”.

[80] BRE (2021) “The cost of poor housing in England”.

[81] Winther, T. and Wilhite, H. (1) “An analysis of the household energy rebound effect from a practice perspective: Spatial and temporal dimensions” Energy Efficiency, 8(3), pp. 595–607.

[82] Liddell, C. and Morris, C. (2010) “Fuel poverty and human health: A review of recent evidence” Energy Policy, 38(6), pp. 2987–2997.

While this has a financial impact and may be pushing many into fuel poverty, they appear more likely to heat their home.

The household groups most affected by this are likely to be households who are ‘financially struggling’ and just about getting by. They are the group taking most actions to reduce heat and have the biggest reductions in consumption. While some also take actions to mitigate this, NGED and other stakeholders should continually consider the advice that they offer to help ensure these customers can remain warm for as low a cost as possible.

This illustrates the awful trade-off that many households faced this winter between either being pushed into fuel poverty by rising energy bills or underheating their homes, with all the associated health and comfort issues. Stakeholders in the sector that have responsibility for customers in vulnerable situations should continue to seek to alleviate these outcomes where possible.

6 Acknowledgements

The analysis in this report uses the Smart Energy Research Lab (SERL) Observatory dataset and data from a follow-up survey of the SERL Observatory panel of 12,000 households, which was conducted early in 2023 with the aim of understanding how the cost-of-living crisis was affecting households across Great Britain.

The SERL Observatory dataset is collected, managed and provisioned to the UK research community via funding from the SERL UKRI grant (EP/P032761/1), see citation below.

The follow-up survey was conducted by a UCL research project that received UCL ethics approval and was led by UCL researchers Dr. Gesche Huebner and members of the Smart Energy Research Lab (Tadj Oreszczyn, Simon Elam, Ellen Zapata-Webborn, Jessica Few, Martin Pullinger, Clare Hanmer, and Eoghan McKenna). The design and fieldwork of the survey was funded by the CREDS UKRI grant (EP/R035288/1), the Project VENICE NIA grant (NIA_WPD_059), and the SERL UKRI grant (EP/P032761/1).

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The full citation for the SERL Observatory dataset is:

Elam, S., Webborn, E., Few, J., McKenna, E., Pullinger, M., Oreszczyn, T., Anderson, B., Ministry of Housing, Communities and Local Government, European Centre for Medium-Range Weather Forecasts, Royal Mail Group Limited. (2023). Smart Energy Research Lab Observatory Data, 2019-2022: Secure Access. [data collection]. 6th Edition. UK Data Service. SN: 8666, DOI: http://doi.org/10.5255/UKDA-SN-8666-6

More information about the SERL Observatory, including information on accessing the data, can be found at https://serl.ac.uk.

The SERL Observatory includes European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 data. Neither the European Commission nor the European Centre for Medium-Range Weather Forecasts is responsible for any use that may be made of the Copernicus information or data it contains.

Annex A – Existing literature on the impact of the cost-of-living crisis on energy consumption

In this Annex we consider the literature review (summarised in Section 2.3) in more detail. This annex is structured as follows.

- First, we consider the overall relationship between changes in energy prices (or changes in customer income) and changes in domestic energy consumption. This can help us understand what the impact of the cost-of-living crisis might have been over the winter period 2022/23. This section also describes the types of actions that customers may undertake to achieve reductions in energy consumption.
- Then we consider the extent to which different customers responded to the crisis. We define the different customer groups of interest and then consider the different actions these groups might take. The customer groups include:
    - different socio-economic groups, focusing on different categories of vulnerable customer;
    - customers who showed persistent behaviour change in response to the COVID-19 pandemic; and
    - customers who are in or close to fuel poverty, defined as when a "*household is unable to afford to heat (or cool) their home to an adequate temperature*".[83]
    - We also consider the difference in demand changes for gas versus electricity.
- Finally, we consider what the expected impact of different actions might be on consumption and bills.

A.1 The relationship between energy consumption and prices

In this sub-section we consider the relationship between energy consumption and prices to understand how, theoretically, a large change in energy prices and customer incomes might affect consumption at a population level. We then consider the guidance available to customers regarding reducing consumption and the studies that attempted to analyse the types of actions customers did and consumption changes.

The historic relationship between energy consumption and prices

As illustrated in Figure 6, before the current crisis energy prices have been stable in the UK. As such, there is limited contemporary academic literature on how household consumption responds to price shocks in the UK. However, in 2016 the Department of Energy and Climate Change (DECC) published an annex to a report on the available evidence on the impact of

[83] Ofgem. December 2018. *Options for the Fuel Poor Network Extension Scheme in RIIO-GD2.*

gas prices on domestic consumption in the UK.[84] This estimates the long-run price elasticity of domestic gas consumption in the UK over the 2005-2012 period. It finds that for every 10% that price increases, gas consumed declines by 1%, implying that demand for domestic gas is relatively insensitive to prices. As this is a long-run estimate, it also captures the effect of any investments made as a result of a sustained price movement on the energy consumed (for example the installation of energy efficiency measures), so we might expect short-run responses to price changes to be different.

Reiss and White (2008), describes the short-run impact of energy price increases.[85] They were able to analyse how household energy consumption responded to a sharp rise in energy prices in San Diego in 2000. They found that following the sharp rise in energy prices, households reduced their electricity consumption on average by 13% against previous years. Their results also show that households respond quickly to rising bills as this effect was experienced in just 60 days following the spike in bills.[86]

We can also look at the impact of income on household energy consumption to infer how households may respond to the current crisis where household real incomes have reduced.[87] A recent UK focussed study looked at the determinants of household gas consumption. It found that demand for gas increased with gross annual household income.[88] Specifically, a 1% increase in household income results in a 0.05% increase in gas consumption. This finding is consistent with previous studies, including Druckman and Jackson (2008)[89] who examined household energy consumption across areas with contrasting levels of deprivation. They found that higher incomes increase energy consumption, though other socio-economic factors are also important.[90]

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84 Department of Energy & Climate Change. June 2016. *Gas price elasticities: the impact of gas prices on domestic consumption – a discussion of available evidence: Annex D.*

85 Reiss, P.C. and White, M.W., 2008. What changes energy consumption? Prices and public pressures. *The RAND Journal of Economics*, 39(3), pp.636-663.

86 The study goes further, identifying a rebound effect in consumption. When an energy price cap was subsequently introduced, households quickly reversed their consumption behaviour. The rebound effect is not absolute and reverses only two thirds of the consumption reduction following the price spike, in part explained by the capped price remaining above the previous stable price before the crisis.

87 See section 2.1 for discussion of impact the impact of the cost-of-living crisis on household real incomes.

88 Fuerst, F., Kavarnou, D., Singh, R. and Adan, H., 2020. Determinants of energy consumption and exposure to energy price risk: A UK study.

89 Druckman, A. and Jackson, T., 2008. Household energy consumption in the UK: A highly geographically and socio-economically disaggregated model. *Energy policy*, *36*(8), pp.3177-3192.

90 Further studies finding a positive relationship between income and energy consumption include;

Abrahamse, W. and Steg, L., 2009. How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings?. *Journal of economic psychology*, 30(5), pp.711-720.

Brounen, D., Kok, N. and Quigley, J.M., 2012. Residential energy use and conservation: Economics and demographics. *European Economic Review*, 56(5), pp.931-945.

Wyatt, P., 2013. A dwelling-level investigation into the physical and socio-economic drivers of domestic energy consumption in England. *Energy Policy*, 60, pp.540-549.

Official guidance relating to the cost-of-living crisis

While the papers above confirms that customers may respond to higher energy prices by reducing consumption, they do not set out *how* this is done. The actions that customers take are likely to be specific to different countries (for example, due to different climates and heating technologies). Several sources give specific energy saving guidance to households, including from Ofgem, the government and other consumer bodies.[91] These are therefore likely actions that UK customers will undertake. Ofgem[92] outlines four types of actions that households may take:

- **Set and forget.** These require one-off actions by households, which have lasting effects on the level of consumption and typically have no financial cost. Examples given include reducing boiler flow temperature on a combi boiler to 60°C; reducing hot water temperature to 60°C; and lowering the temperature on a room thermostat.

- **Everyday small actions.** These actions include changing behaviour on a daily basis and typically involve reduced use of appliances. Their impact on consumption is usually only whilst the action is being taken. Examples given include reduced use of tumble dryers; turning appliances off rather than leaving them on standby; and closing curtains/blinds at night.

- **Basic home improvements.** Some smaller home improvements can improve energy efficiency. Examples given by Ofgem include switching to energy efficient lightbulbs; installing smart meters; and insulating hot water tanks/cylinders.

- **Larger home improvements.** These actions are also targeted to improving energy efficiency but are likely to have larger impacts as well as greater up-front costs. Examples include loft insulation; upgrading to double (or triple) glazing; wall/cavity and underfloor insulation.

The UK Government also published energy saving advice as part of its 'Help for Households' campaign.[93] It groups the advice in a similar way to Ofgem, focusing on: 'Quick and easy no cost actions'; 'Low-cost home improvements'; and 'spend-to-save home improvements'. Most of the included actions are also covered by Ofgem, with the addition of more home improvement options; installing solar panels; installing a smart thermostat; and insulating hot water cylinders. Each tip is accompanied with the average expected saving in pound terms a household could make by taking the action.[94]

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91 Citizens Advice and the Energy Savings Trust offer tips for saving on energy bills in response to the cost-of-living crisis

92 Ofgem, 2023. *Actions for saving energy*.

93 UK Government. 2023. *Help for Households, Energy saving tips to save money.*

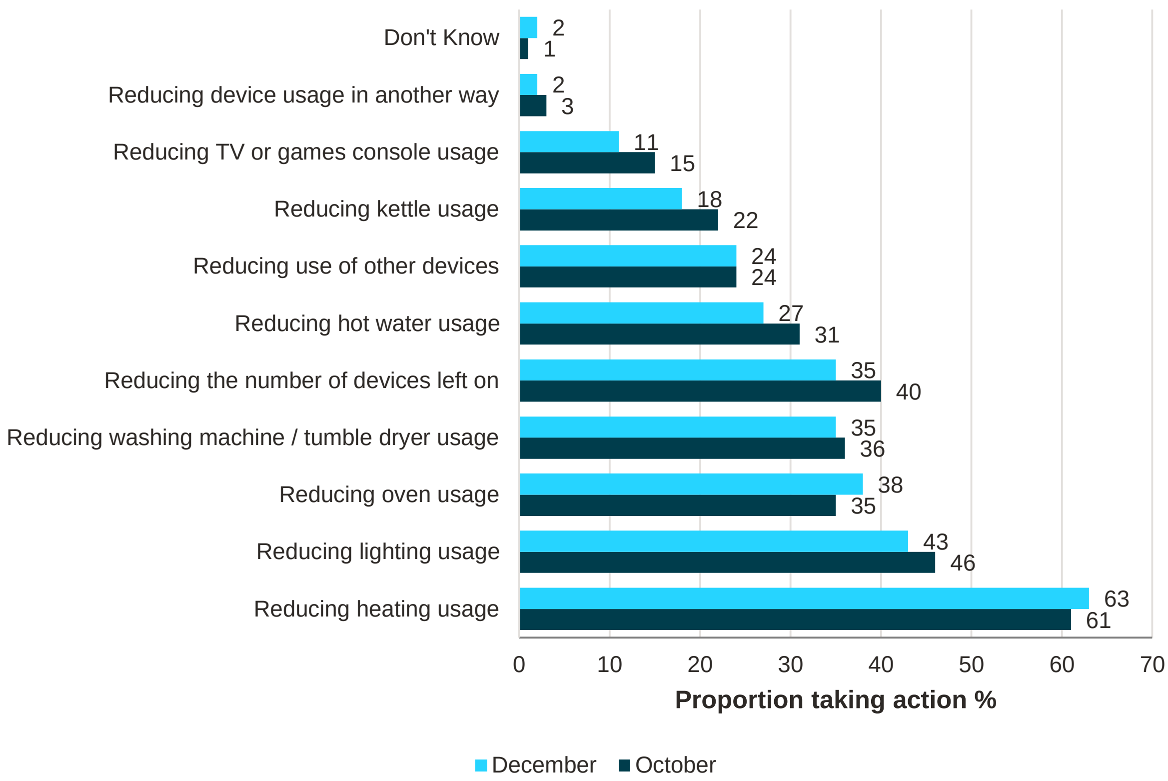
94 See Figure 8 for more detail on the expected impact of these actions is included in section 2.2.3.

Analysis relating to actions taken during the current cost-of-living crisis

There have been a few reports that have considered the impact of the current cost-of-living crisis on energy consumption.

YouGov surveyed households on their energy consumption in October and December 2022. Looking at the results of the December survey, 73% of households reported reduced gas and electricity consumption compared to normal usage, with the most common action taken to achieve this being reduced heating usage (63%). Both surveys asked what areas the public were cutting back on energy uses and the specific actions taken by those who looked to reduce consumption in that area. The main actions surveyed, and the percent of population reported to take them in each wave of the survey, are illustrated in Figure 28 Areas in which Britons have been cutting back use of electric or gas devices.

Figure 28 Areas in which Britons have been cutting back use of electric or gas devices



Source: Frontier Economics visualisation of YouGov data[95]

Note: Fieldwork 9 – 11 December for December survey, 3 – 4 October for October survey

[95] YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

We can examine whether the actions people were taking had been impacted by the cold weather and moving further into winter by comparing to the results of the October YouGov survey. Similar proportions reported that they were reducing their use of gas and electricity devices (both 73%) and reduced heating usage was again the most popular action taken to do this in both surveys (rising slightly from 61% to 63%).[96] We also see that similar proportions of respondents took other energy saving measures in each of the October and December surveys.

The Energy System Catapult (ESC) analysed changes in gas consumption in September and October 2022 for 36 homes that were part of the ESC's *Living Lab* households. The study found that participants were using 40% less gas and homes being kept on average 0.6 °C colder compared to the same period last year. However the study notes some caveats to the results: it is a small sample size and the sample is not representative of the UK population; and the analysis considers the autumn period, acknowledging that behaviour may change in the winter.[97]

The International Energy Agency considered behavioural changes, rising fuel poverty and fuel-switching in the residential sector to reduce gas demand across the European Union.[98] The study attempted to disentangle weather, behavioural and efficiency effects on decreased gas consumption. Data from a sampling of smart thermostat providers suggests that customers adjusted their thermostats lower by an average of around 0.6°C (which is consistent with the ESC finding). Fuel poverty was another factor: many customers in vulnerable situations reduced consumption because they could not afford the higher bills, leading to cold homes or a shift to cheaper and sometimes more polluting fuels such as wood pellets, charcoal, waste or low-quality fuel oil.

A.2 Variations in household actions in response to the cost-of-living crisis

While the previous section looked at the relationship between price and consumption across all customers, we are also interested in the impact of price changes on different customer groups. Based on the questions of interest for this study (set out in Section 1) we focus on the following customer groups:

- Different socio-economic groups and particularly the customers in socio-economic groups Ofgem considers to be most vulnerable. We focus on the following types of customers in vulnerable situations:
  - Customers that are eligible for the Priority Services Register (PSR).[99]

96 YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

97 Energy Systems Catapult. *Measuring the Consumer Response to the Energy Crisis in the Living Lab.*

98 International Energy Agency.14 March 2023. *Europe's energy crisis: What factors drove the record fall in natural gas demand in 2022?*.

99 Ofgem. *Get help from your supplier – Priority Services Register.*

  - Customers in fuel poverty which considers customers with poor energy efficiency in their homes and customers who are struggling financially.
- Customers with persistent behaviour change as a result of the COVID-19 pandemic. These are typically customers that started working from home during the pandemic and maintained that working pattern afterwards.

Different socio-economic groups

There are many different socio-economic groups that we might want to consider in this analysis. However we choose to narrow our approach. First, we focus on customers in vulnerable situations, as these customers are of most interest to this study. Ofgem considers there to be a wide variety of vulnerability types; in their Vulnerability Report (2019) it considers over 20 types of vulnerability.[100] Therefore we focus on only the set of customers that are most likely to be at risk following the cost-of-living crisis, particularly since Ofgem also notes that many customers in these categories may not feel that they are vulnerable. We also want to ensure that we can identify customer groups in the data.

A more concise list of customers who might require extra help as a result of the cost-of-living crisis would be those on the Priority Services Register (PSR).[101] The PSR is a free support service that makes sure extra help is available to people in vulnerable situations. We use this list of criteria to identify a subset of socio-economic groups that have differing patterns of consumption or requirements for heat and thus might be most exposed to changes in energy prices.[102] When considering the types of customers on the PSR, there are three groups that are particularly relevant in the GB population. These are:

- households with elderly members;
- households with members that are long term sick, suffering from health issues or living with disabilities; and
- households with young children.

We also focus on households in fuel poverty. Fuel poverty is defined by a combination of low energy efficiency and low income. Therefore we consider households within different building types and households that are struggling financially.

Finally, we consider two groups which, while not directly indicators of vulnerability, may be correlated with aspects of vulnerability and might have different responses. These are:

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100 Ofgem. 25 October 2019. *Consume Vulnerability Strategy 2025.*

101 Ofgem. *Get help from your supplier – Priority Services Register.*

102 Some of the PSR groups relate to specific needs such as struggling to answer the door in an emergency or requiring electricity for medical equipment. Such groups may be more vulnerable to interruptions in their energy supply; however these types of vulnerabilities are less likely to affect households' response to higher prices.

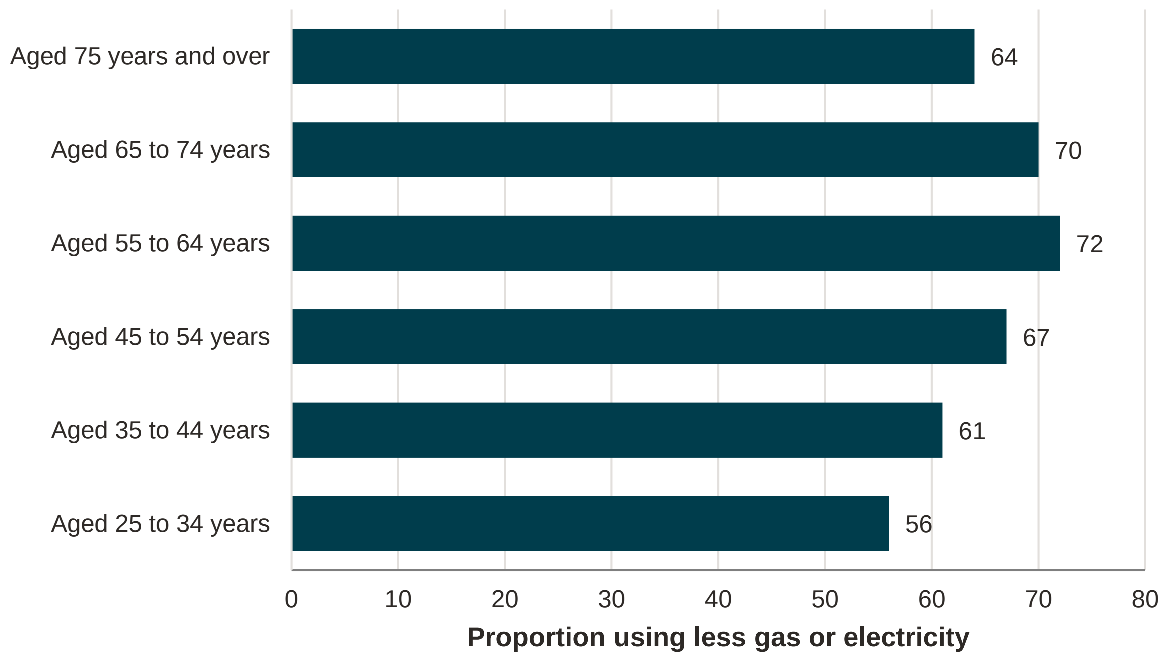
- Households in different types of building tenure. Those in social housing may be more likely to be vulnerable and those in rented homes may not be able to choose their own appliances.
- Households with members who work from home. As described in section 2.2, such households may have the option of working from a workplace to reduce bills.

We assess each of these customer groups, and customers with persistent behaviour change as a result of the COVID-19 pandemic, in turn.

Households with elderly members

Evidence suggests older adults are more likely to reduce energy consumption in response to price rises, but only up to a point. After which, the most elderly are less likely to use less energy. The ONS Winter Survey examines how people are coping with various winter pressures, including cost of living rises and access to health services. It found that adults aged 55 to 74 were most likely to reduce energy usage in response to the cost-of-living crisis. Within this range, those aged 55 to 64 were more likely to reduce usage than those 65 to 74, who in turn were considerably more likely to report reduced usage than those aged 75 years and over, as illustrated in Figure 29.

Figure 29 Proportion of adults reducing energy use by age of respondent



Source: Frontier Economics illustration of ONS data[103]

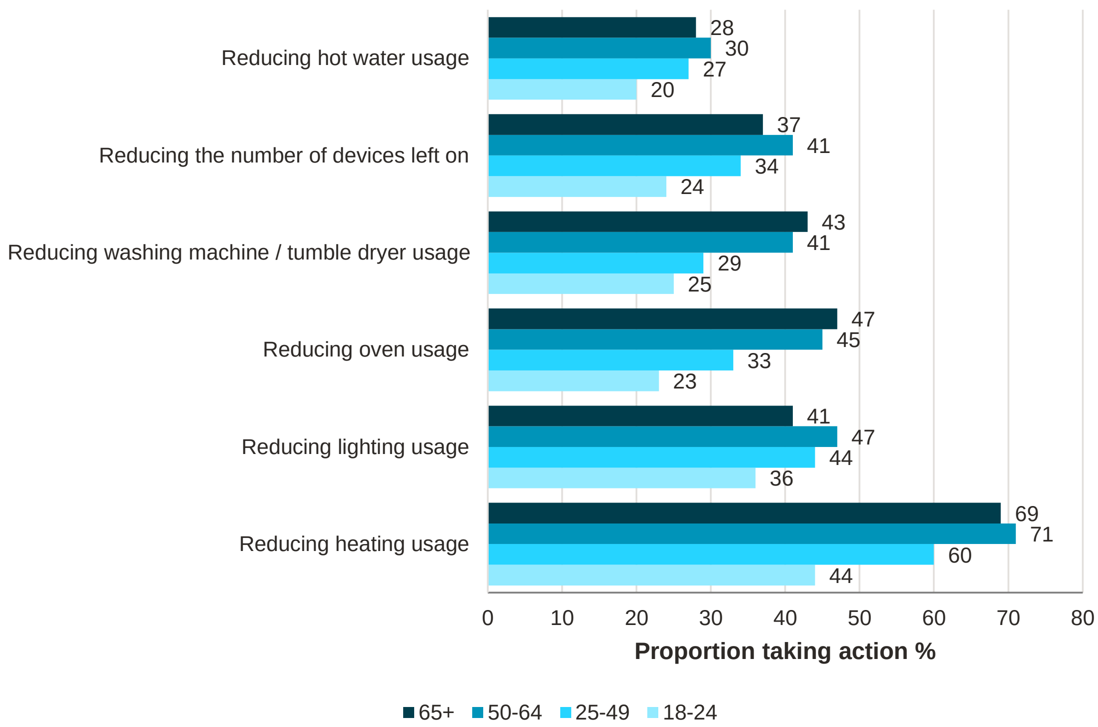
[103] Office for National Statistics. 20 February 2023. *Impact of increased cost of living on adults across Great Britain: September 2022 to January 2023.*

Note: Survey period September 2022 to January 2023

In the YouGov survey, there is some evidence on which actions are taken by different age groups. However, this only takes into account the ages of the adult who responded to the survey, rather than others in the household.[104]

Figure 30 shows that older households are typically more likely to take action to reduce energy consumption at home, which supports the ONS finding that older adults are more likely to reduce consumption. There are two actions (reduce washing machine / tumble dryer usage; and reduce oven usage) where respondents aged 65 and over are the most likely age group bracket to perform the actions. In addition, there are another three actions (reducing hot water usage; reducing the number of devices left on; and reducing heating usage) where respondents aged 65 and over are the second most likely age group bracket to perform the actions.

Figure 30 Actions taken by UK adults to reduce energy consumption at home by age group bracket



[104] It therefore does not capture the composition of the rest of the household which may be an important determinant on the likelihood and ability for a household to implement and action and on the estimated effect on consumption of any action taken.

Source: Frontier Economics visualisation of YouGov data[105]
Note: Fieldwork 9 – 11 December 2022

Households with young children

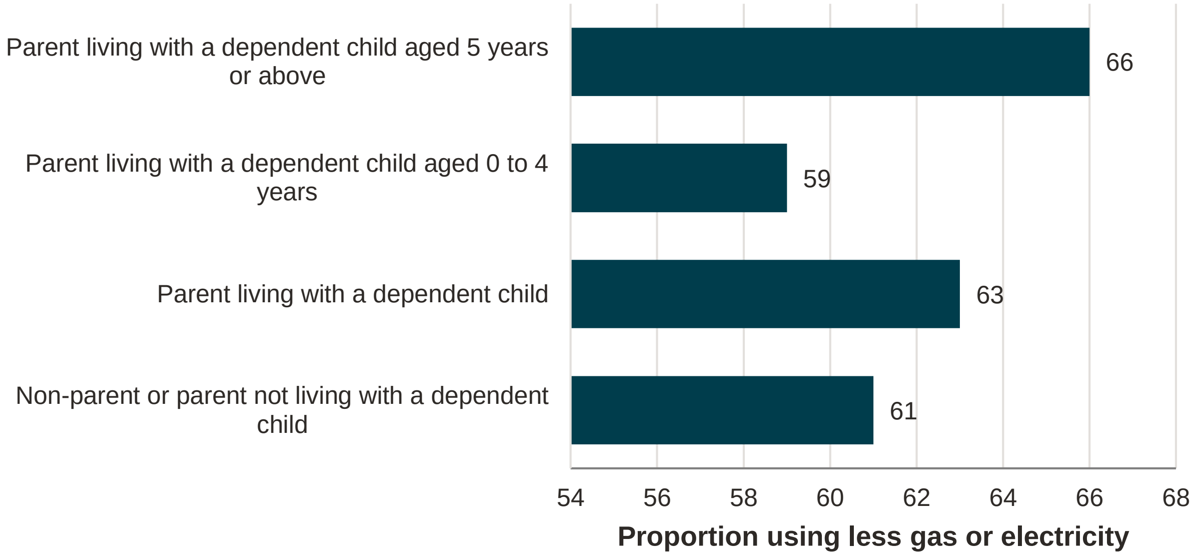
So far, there appears to be limited evidence on the energy saving actions taken by households with young children. It is plausible that parents of young children may feel constrained in the energy-saving actions that they can take (for example, being unwilling to take actions to lower internal temperatures if they feel that this would put their children at risk).[106] However the additional expenditures associated with children could mean that the cost-of-living crisis has had a higher impact on the disposable income of this group, who would then need to find ways to reduce expenditure.

The ONS Winter Survey shows how parents of young children have responded to rising energy costs. As illustrated in Figure 31, it found parents living with a dependent child are more likely to report reduced energy usage when compared to those not living with a dependent child. The results are also disaggregated by the ages of dependent children. This shows that those with children aged under 5 were less likely to reduce energy usage than those with children aged 5 years and above and those without children.

105 YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

106 Academic literature has explored the impact of cold homes on early years development. There is supporting evidence of an increased risk of, amongst others; asthma, respiratory infection and slower cognitive development. See:
Liddell, C. and Morris, C., 2010. Fuel poverty and human health: a review of recent evidence. *Energy policy*, 38(6), pp.2987-2997.

Figure 31 Parents living with a dependent child were more likely to report reduced energy consumption

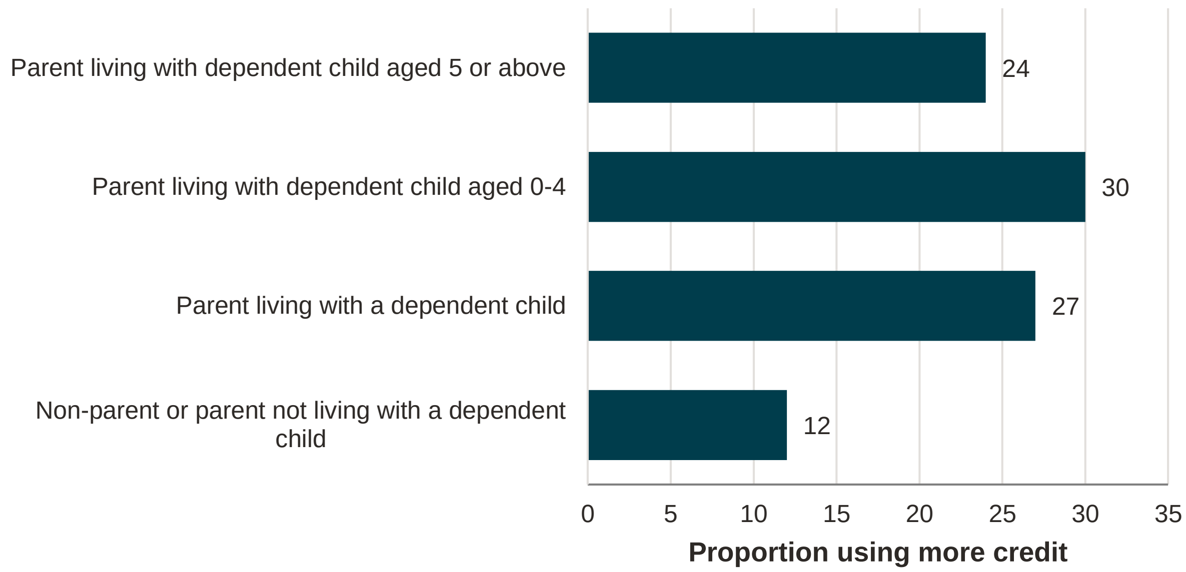


Source: Frontier Economics illustration of ONS data[107]
Note: Survey period September 2022 to January 2023

The same ONS survey also finds that parents living with children under 5 were the most likely group to report having used more credit than usual because of increases in the cost of living, as we see in Figure 32. This finding, combined with parents of the youngest children being the least likely to reduce energy consumption, could support the view that parents of young children feel constrained in the energy-saving actions that they can take without impacting their child.

[107] Office for National Statistics. 20 February 2023. *Impact of increased cost of living on adults across Great Britain: September 2022 to January 2023.*

Figure 32 Parents of children under 5 were the most likely to report using more credit because of the cost-of-living pressures



Source: Frontier Economics illustration of ONS data[108]
Note: Survey period September 2022 to January 2023

Households associated with long term health issues

There is also currently limited evidence on the energy saving actions taken by households containing a person suffering from health issues.

People who are out of work as a result of long-term illness or disability may be more exposed to rising energy costs. This group are likely to have lower household income as they are unable to work, or work fewer hours, and they may also be more reliant on energy. In February 2022, Scope (a charity which provides support to people living with disabilities) found that 43% of disabled adults reported needing to use more energy to meet their needs and that 23% of disabled people were unable to heat their home compared to 10% of non-disabled people.[109]

However, similar to households with children, it is possible that households with ill members will minimise the impact of energy-saving measures (e.g. maintaining a level of heating).

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108 Office for National Statistics. 20 February 2023. *Impact of increased cost of living on adults across Great Britain: September 2022 to January 2023.*

109 Scope. 8 February 2022. *Disabled people hit hardest in the biggest cost-of-living crisis in a generation*.

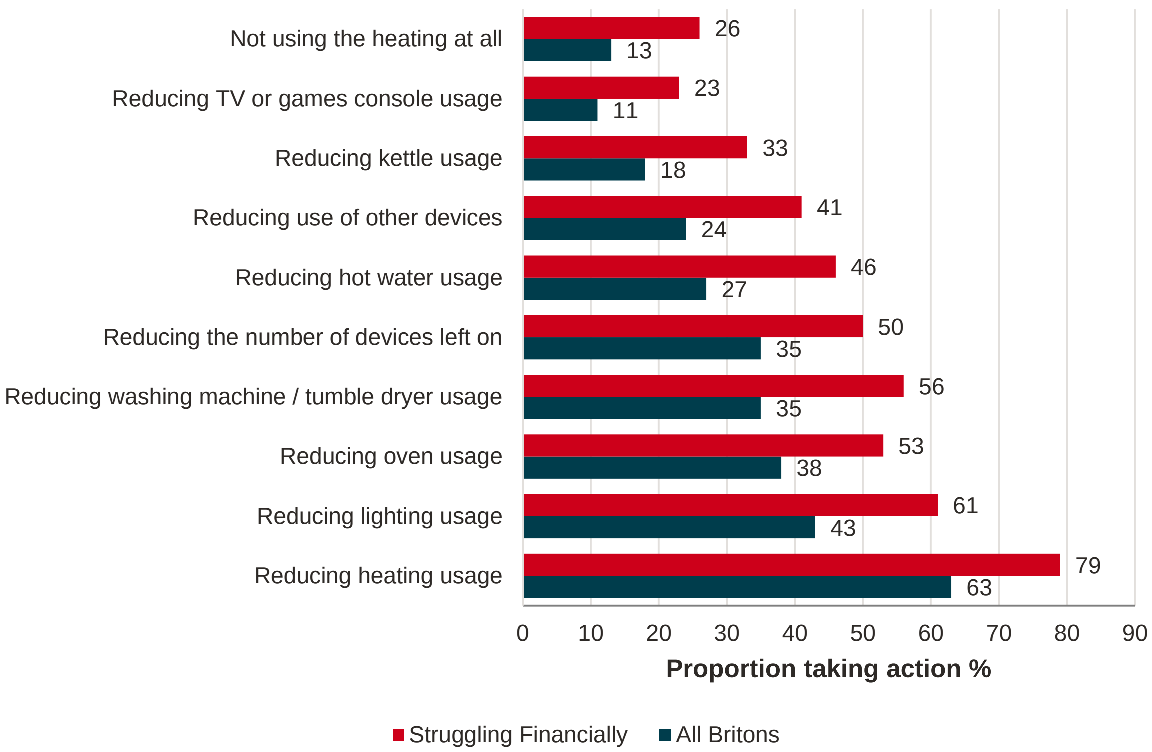
Fuel-poor customers

We are also interested in the impact of the cost-of-living crisis on customers in fuel poverty. YouGov's surveys report results by whether the household is struggling financially. Those on low incomes are more likely to take extreme energy saving actions than the population. Actions that are more likely to be taken by 'financially struggling' households include:

- not using the heating at all;
- reducing lighting usage; and
- reducing hot water usage.

Figure 33 visualises the December survey results, showing the differences in the proportion of those struggling financially taking an action against all Britons.

Figure 33 Those struggling financially are more likely to take action to reduce their energy consumption



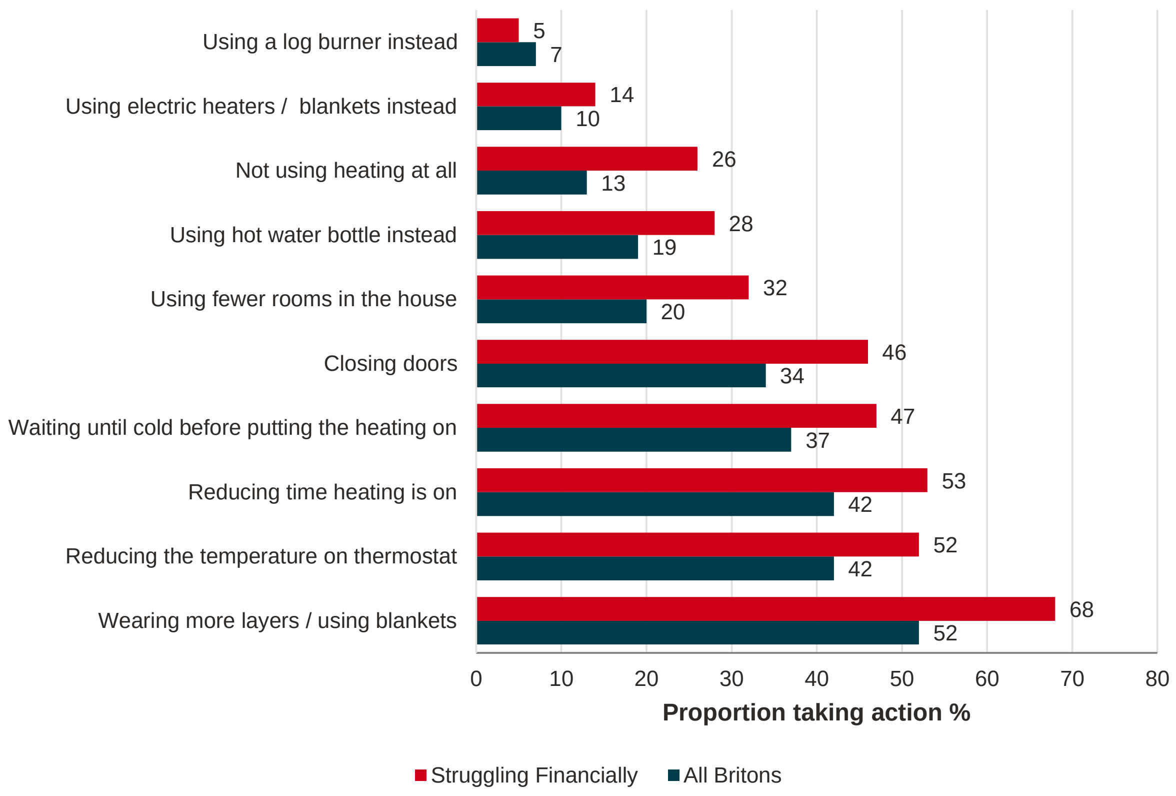
Source: Frontier Economics illustration of YouGov data[110]
Note: Fieldwork 9 – 11 December 2022

[110] YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

Given our findings show that a positive relationship exists between energy consumption and income, these results are unsurprising. Those on lower incomes are likely to have the least disposable income and their financial security is more sensitive to cost-of-living increases – especially household bills. This means that they are less able to afford excess energy consumption and are likely to take more actions to reduce consumption in order to keep their energy bills down.

Of respondents who answered that they were reducing heating usage, a higher proportion of 'financially struggling' households reported taking an action than the general population for all actions other than using log burners as an alternative heat source. These impacts are visualised in Figure 34.

Figure 34 Ways in which 'financially struggling' households have limited heating usage compared to all Britons



Source: Frontier Economics visualisation of YouGov data[111]
Note: Fieldwork 9 – 11 December 2022

[111] YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

The above analysis only considers those who report that they are struggling financially. However, we might want to consider two separate groups: those who were struggling financially prior to the cost-of-living crisis and those who are struggling financially as a result of the cost-of-living crisis. Those struggling financially prior to the crisis may be less able to take actions to save energy in winter, since they might already be taking those actions. However, households struggling financially as a result of the crisis may have the scope to take action to reduce consumption.

Building tenure

Another explanation explored in the literature is that rented dwellings are significantly less likely to have energy efficient appliances installed than owner occupied houses.[112] When a tenancy agreement does not include household bills, the landlord is not exposed to the cost of high energy bills. This removes the incentive for them to invest in appliances or other home improvements that are more efficient. We also see this in more recent ONS data[113] which finds that private rented dwellings have the highest proportion of non-decent dwellings of any housing tenure group in England. Private rented dwellings also have the lowest average energy efficiency and the smallest proportion of household with an energy efficiency rating of band C[114] according to the Standard Assessment Procedure (SAP), as shown in the table below.

Table 7 Energy efficiency of dwellings in England by tenure type

Tenure	Mean SAP rating	Rated C or above	Dwellings in Group (000s)
Owner occupied	65.5	42.3%	15,326
Private rented	64.7	41.8%	4,247
Local authority	69.1	61.2%	1,543
Housing association	70.2	68.3%	2,418
All Social	69.8	65.5%	3,961

Source: UK Government. 17 July 2019. English Housing Survey live tables: Energy Performance.
Note: Data collected 2020.

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112 Souza, M. N. M. *Why are rented dwellings less energy-efficient? Evidence from a representative sample of US housing stock.* Energy Policy, vol 118, pp 149 – 159.

113 ONS, *English Housing Survey 2021 to 2022 headline report,* 15 December 2022.

114 The SAP methodology measures the energy efficiency of homes and underpins the Energy Performance Certificates (EPC) awarded to buildings. Currently, an energy efficiency rating of D or below is part of the criteria for determining fuel poverty in England. The UK Government has a target for all residential properties to have a minimum EPC rating in band C by 2035.

Households in less energy-efficient properties may be more exposed to the rise in fuel prices (as, all else equal, their bills will be higher) and may therefore need to take more drastic actions. However they may also be unable to take some actions (such as upgrading appliance).

Households with members who work from home

Another customer group of interest is those customers who have worked from home during the COVID pandemic and persisted with this behaviour after the pandemic.

Regular home-working has resulted in increased energy consumption, leading to higher energy bills.[115] An ONS report found that around 80% of households who had worked from home in the previous week said they were spending more on utility bills as a result of the COVID-19 pandemic.[116] Therefore, we might expect customers who now work from home to take more actions to reduce energy consumption. However, as an alternative, households could change ‘type’ in response to higher domestic energy costs and return to their place of work more frequently to reduce energy consumption.

The likelihood of customers who work from home to take action, whether energy-saving actions or changing household type (i.e. working from their place of work more often), will depend on household characteristics. For example, if customers working from home are likely to be on higher incomes, these customers might be less affected by rising energy bills.[117]

Relative changes in gas and electricity consumption

The most common reported action among customers to save energy was to reduce heating usage. Therefore we might expect a greater change in gas consumption relative to electricity consumption. However, that depends on the extent to which customers are reducing their heating consumption and which fuel they use to heat their homes.

A good illustration of this is identifying how people were looking to reduce their heating usage from October to December. The YouGov survey asked respondents who reported that they were reducing heating usage what actions they took to achieve this. The options included some actions that directly reduce consumption (such as turning down the thermostat temperature) and others that compensate for the reduced heating usage (such as wearing more layers). The proportion of people who were not using heating at all nearly halved (from

115 Frontier Economics, Zapata-Webborn, E., McKenna, E. (2023) Project VENICE: The impact of the pandemic on electricity consumption.

116 ONS 1 February 2022. *Energy Prices and their effect on households*.

117 The ONS opinions and lifestyles survey found that professionals and workers with a degree recorded the highest levels of hybrid of home working in the UK in the winter of 2022/23. Source: ONS. 13 February 2023. *Characteristics of homeworkers, Great Britain: September 2022 to January 2023.*

25% to 13%) while other actions to reduce heating usage became more popular, reflecting a change in how people were looking to reduce usage.

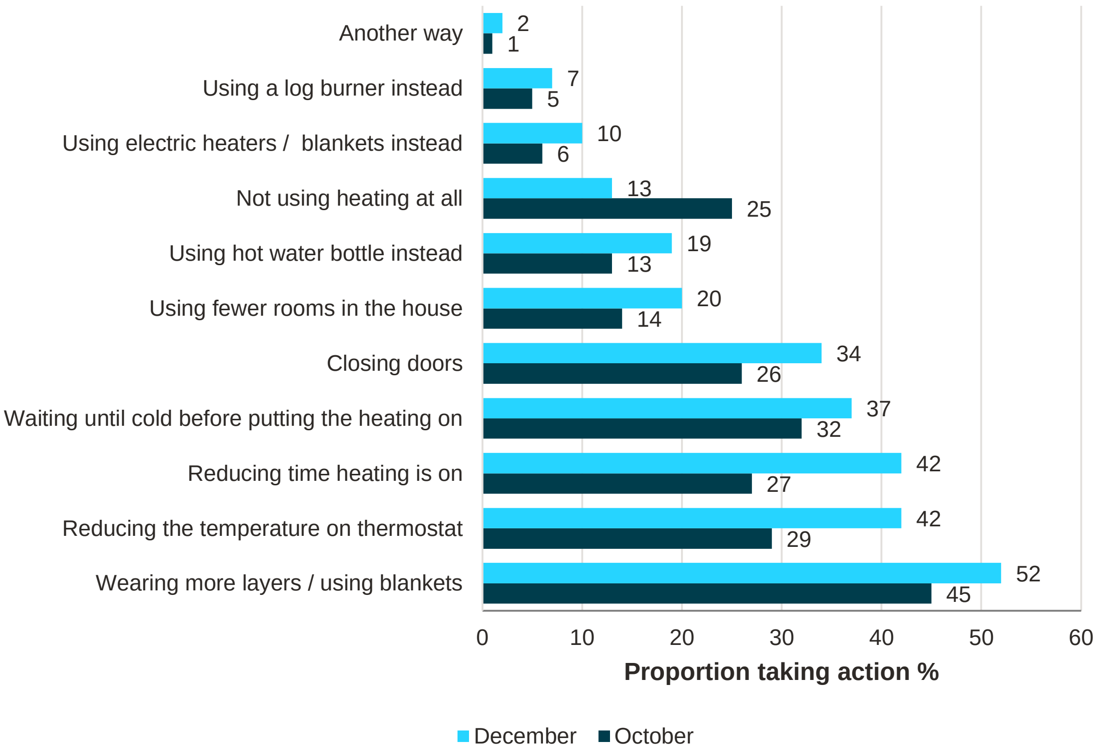
These actions included:

- reducing the temperature on thermostat;
- reducing the time heating is on; and
- using fewer rooms in the house.

The data suggests that people substituted other energy saving actions in place of not using their heating at all, as fewer people were prepared to go without any heating in the colder months. These actions include a mix of ‘set and forget’ actions as well as everyday behaviour changes. This suggests that gas consumption might face larger decreases over the winter period than electricity.[118] A comparison of the October and December results is shown in Figure 35.

118 This will depend on the proportion of households that heat their homes with electricity compared to gas or other types of fuel.

Figure 35 The actions people are taking to specifically reduce heating usage



Source: Frontier Economics illustration of YouGov data[119]
Note: Fieldwork 9 – 11 December for December survey, 3 – 4 October for October survey

The survey shows that around 2 in 10 adults reported that they were not always able to keep comfortably warm in the preceding two weeks. The results for the January 2023 wave were slightly lower (19%) than the previous wave of the survey in December 2022 (22%)[120], though the ONS note that these results can be affected by strong seasonal spending patterns relating to gas and electricity. This corroborates the evidence from YouGov that some customers may have been significantly reducing their heating demand.

A.3 Expected impact of energy saving actions

One of the key parts of our modelling work is attributing the impact of energy-saving actions to changes in household consumption. To help come up with some initial hypotheses to test, we want to understand the expected impact of energy saving actions.

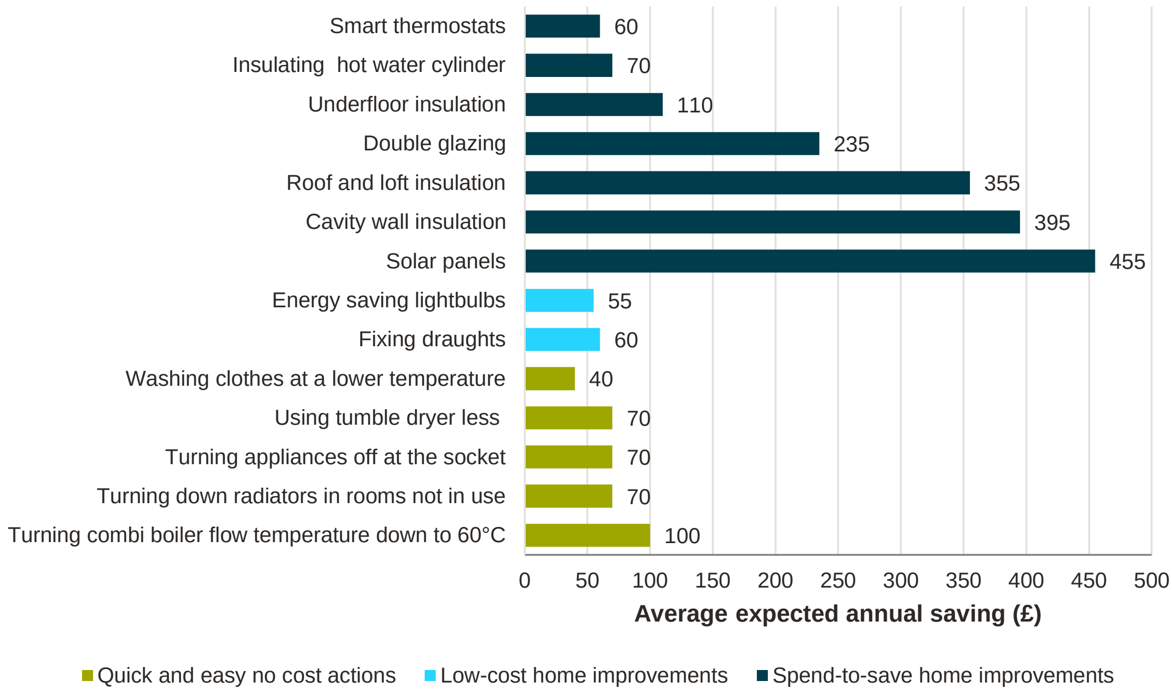
Where advice has been given to households on how to cut down energy consumption, it is often accompanied with estimates of expected average savings that each action could make

119 YouGov. 14 December 2022. *Six in ten are reducing their heating usage, despite recent cold weather.*

120 ONS. 27 February 2023. *Tracking the impact of winter pressures in Great Britain: 18 to 29 January 2023*. 27 February 2023.

over the course of a year. The UK Government provides tips for energy saving along with an estimate of the average expected saving that can be made by following an action. The estimates given are illustrated in Figure 36.[121]

Figure 36 Average expected annual savings from energy saving actions from Help for Households advice



Source: Frontier Economics illustration of UK Government Help for Households advice estimates.[122]
Note: Actions are grouped as they appear in the Help for Households advice.

At a high level, we see that the most effective actions in terms of money saved on energy bills tend to be higher cost, such as insulation and the installation of solar panels and double glazing. We also see that substantial savings can be made by implementing no-cost 'set and forget' actions.

In addition, the Energy Saving Trust also published advice to households on reducing bill impacts of heating, along with some estimated expected savings.[123] It estimates that turning the temperature down on a thermostat could save £145 a year. Insulating radiators with

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121 There is however significant uncertainty involved in these estimates and the effects are likely to vary significantly by household.

122 UK Government. *Help for Households: Energy saving tips to save money.*

123 Energy Saving Trust. November 2022. *Warm Home Hacks.*

reflective panels could also be a low-cost home improvement. For five radiators, this could cost around £30 but save £40 each year.

Perceptions of effectiveness of energy saving actions

Whilst there are published estimates that estimate the impact of energy-saving actions, households do not necessarily know what actions are most effective. Research by the Behavioural Insights Team, published by the charity Nesta, finds:

> *"Concerns about higher energy bills have pushed almost all households in the UK (98%) to try to save energy in at least one way. But despite most people trying at least one energy-saving measure, many still don't know which are the most effective."*

It asked survey respondents to rate eleven energy saving actions by how much they saved in monetary terms and compared the results to estimated impacts of each action.[124] The findings show that customers can considerably misjudge the effectiveness of different energy saving actions. The perceived most effective action was air drying laundry (as opposed to using a tumble dryer) which is estimated to save approximately £70 annually. However, the estimated most effective action – turning the thermostat temperature down 2°C – could save £309 per year. Despite this, it was ranked fourth in terms of perceived annual impact by respondents. The full results of this experiment are detailed in Table 8.

Some further key findings include:

- Taking showers instead of baths and turning off lights were both rated fifth highest for potential savings despite being the least effective based on estimated impact.
- People perceive there to be little variance in effectiveness of different actions, but in reality, there are savings ranging from £16 to £309 a year.

This suggests that customers may choose to take actions that are less effective at reducing consumption. Therefore we might observe some customers that take a number of actions, but their energy consumption does not reduce.

[124] The estimates for potential monetary savings are taken from research undertaken by Cambridge Architectural Research in 2012 and updated for 2022. Full results of the 2022 study can be accessed at: Nesta. 10 October 2022. *Free and low-cost energy-savings actions to bring down bills, improve energy security and help the planet.*

Table 8 Perceptions of effectiveness of energy saving actions do not align with the estimated impact of those actions

Action	Perceived potential energy saving ranked highest potential (1) to lowest (11)	Approximate saving on typical bill (£ per year)
Air drying laundry instead of using the tumble dryer	1	70*
Wear warmer clothes at home and set thermostat lower than usual	2	153
Delay the time of time of year that you turn on the heating until necessary	3	67
Turn down the thermostat (by 2°C)	4	309
Turn off the lights when they are not in use	5=	25
Take showers instead of baths	5=	16
Turn down radiators in unused rooms	7	68
Service and maintain heating system	8	39
Turn down the boiler flow temperature on a combi boiler	9=	112
Insulate hot water pipes	9=	26
Install a water-efficient shower head	11	83

Source: *Nesta. 3 January 2023. Almost all household have taken at least one energy-saving measure amid fear of permanently higher energy bills.*

Note: *Approximate estimated annual savings for each action are given in data labels. Note that the ranking of potential energy savings does not follow the ranking of approximate estimated impact in all instances*

Annex B – Counterfactual methodology

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University College London, 2023

B.1 Introduction

In this Annex we describe the counterfactual (predictive) modelling used to estimate what electricity and gas consumption would have been had conditions in October – December 2022 been the same as in October – December 2023 (accounting for differences in weather). We begin by describing the datasets used, followed by the counterfactual modelling process including models used, model selection and evaluation and finally potential weaknesses and considerations for interpreting the results.

B.2 Datasets

The Smart Energy Research Lab (SERL)[125] started recruiting households in Great Britain in 2019 in order to collect their half-hourly electricity and gas smart meter data for research[126] [127]. Data collection[128] is ongoing with data for some of the first participants recruited dating back to August 2018. When signing up participants were requested to complete a survey about their home and household, and in January 2023 participants were sent a follow-up survey to refresh the key survey information and ask about the cost-of-living crisis and measures taken to reduce energy use. In addition to the smart meter and survey data, hourly reanalysis weather data from the European Centre for Medium-Range Weather Forecasts (ECMWF)[129] and Energy Performance Certificate (EPC) data are linked at the household level, along with region and index of multiple deprivation (IMD) quintile.

These datasets are available to accredited researchers via a secure-lab environment following a project application for research in the public interest. Projects require university ethics approval, approval by the SERL Data Governance Board, and accredited researcher status

125 www.serl.ac.uk

126 Webborn, E., McKenna, E., Elam, S., Anderson, B., Cooper, A., & Oreszczyn, T. (2022). Increasing response rates and improving research design: Learnings from the Smart Energy Research Lab in the United Kingdom. Energy Research & Social Science, 83, 102312

127 Webborn, Ellen, Jessica Few, Eoghan McKenna, Simon Elam, Martin Pullinger, Ben Anderson, David Shipworth, and Tadj Oreszczyn. "The SERL Observatory Dataset: Longitudinal smart meter electricity and gas data, survey, EPC and climate data for over 13,000 households in Great Britain." Energies 14, no. 21 (2021): 6934

128 Elam, S., Webborn, E., Few, J., McKenna, E., Pullinger, M., Oreszczyn, T., Anderson, B., Ministry of Housing, Communities and Local Government, European Centre for Medium-Range Weather Forecasts, Royal Mail Group Limited. (2023). Smart Energy Research Lab Observatory Data, 2019-2022: Secure Access. [data collection]. 6th Edition. UK Data Service. SN: 8666, DOI: http://doi.org/10.5255/UKDA-SN-8666-6

129 https://www.ecmwf.int/

for all those with data access. For more information about how to access SERL data visit the SERL website.

Data filtering

Smart meter data was used at daily granularity – the sum of half-hourly reads (if valid and available); otherwise the daily read. Going forward we refer to these reads as 'daily reads'. Electricity and gas were treated separately and the data filtering applies to each fuel separately (we use the term 'energy' to indicate either. In every model training month (October 2021 – March 22) participants were required to have at least 25 days' daily energy read available. They were also required to have all 92 daily reads available in the cost-of-living crisis period studied (1st October 2022 – 31st December 2023). These filtering criteria reduced the samples to 7446 electricity households and 6998 gas households (additional filtering was also applied at the modelling stage to remove households with inaccurate models; more details below).

Data preparation

Calendar variables

We add two variables to capture the cyclical nature of the year (i.e. that 31st December and 1st January are approximately the same rather than polar opposites):

$$\text{sin\_day} = \frac{1}{2}\sin\left(\frac{2\pi d}{D}\right) + \frac{1}{2}$$
$$\text{cos\_day} = \frac{1}{2}\cos\left(\frac{2\pi d)}{D}\right) + \frac{1}{2}$$

where d is the position of the day in the year (*i.e.* 1st Jan has d = 1) and D is the total number of days in the year (365 or 366). We normalised the sinusoidal transformations (restricted to between 0 and 1). Weekday, weekend and bank holiday flags were also added for potential use in the models.

Weather data

The ECMWF reanalysis weather data has no missing values. The following variables were selected for use in the models (although not all included in all models):

- Temperature at 2m above surface level in °K
  - Daily mean, daily maximum, daily minimum, and daily mean on each of the three preceding days
- Solar radiation (cumulative from the preceding hour) in Jm^{-2}
  - Daily mean and daily mean on each of the three preceding days
- Total precipitation (cumulative from the preceding hour) in m

  - Daily mean

- Wind speed (in m^{-1}) taken from two perpendicular components

  - Daily mean and daily maximum

B.3 Counterfactual modelling

Introduction

What impact did the cost-of-living crisis have on domestic energy consumption this winter? To answer this question, we construct 'counterfactuals' (or a 'baseline') which estimates/predicts what each household in our sample would have consumed had conditions been the same as last winter (accounting for differences in weather conditions). We have previously constructed counterfactuals to estimate the impact of the COVID-19 pandemic on energy consumption[130] [131]. Given the success of our previous analysis, we apply very similar methods here.

To determine the baseline for each household we developed four types of models previously used for predicting domestic electricity demand. These models use data from the period October 2021 – March 22 which we take to be before the cost-of-living crisis to learn the relationship between electricity or gas consumption and the calendar and weather variables. Each household is modelled separately to allow for different relationships between the independent and dependent variables. Different variations of the models were compared to find the one with the lowest error for each household, so not only does each household have a different model, but they can have different types of model according to which worked best for each household. The types of model tested were (including variations of each): elastic net regression, linear regression, neural networks, and extreme gradient boosting. The models output a set of daily energy consumption predictions (in kWh) for each household for each day in October – December 2022.

Elastic net regression

Introduction

Regression analysis seeks a functional relationship between response variable(s) (in this case electricity consumption) and predictor/independent variables (such as weather or day of the week). Linear regression is a regression that assumes a linear relationship between predictor and response variables. Linear regression models are the simplest family of predictive models

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[130] Frontier Economics, Zapata-Webborn, E., McKenna, E. (2023) Project VENICE: The impact of the pandemic on electricity consumption. https://www.nationalgrid.co.uk/downloads-view-reciteme/627612

[131] Zapata-Webborn, Ellen, Martin Pullinger, Eoghan J. McKenna, Callum Cheshire, Harry Masters, Alex Whittaker, Jessica Few, et al. 2023. "The Short- and Long-term Impacts of COVID-19 on Household Energy Consumption in England and Wales." OSF Preprints. March 21. doi:10.31219/osf.io/m5p3b

and are therefore a good place to start. Challenges for regression include 'over-fitting'[132] and lack of model. Using a regularisation (or 'shrinkage') method with regression is a way to penalise large coefficients and/or the inclusion of many predictor variables, which can help address these issues. Regularisation reduces model variance at the expense of a small increase in model bias. Three methods are available: ridge regression which penalises large coefficients (but not to zero), lasso regression which penalises a large number of predictor variables, and elastic net regression[133]; a combination of the two. Elastic net regression has previously been found to outperform other methods for electricity consumption prediction[134] and so this was the first model we developed and tested. In elastic net regression, for n response data points y_i, and p predictor variables x_j, the coefficients β_j for each predictor that are determined by minimising the residual sum-of-squares plus the elastic net penalty:

$$\sum_{i=1}^{n}\left(y_i - \beta_0 - \sum_{j=1}^{p}\beta_j x_{ij}\right)^2 + \lambda\sum_{j=1}^{p}\left(\alpha\beta_j^2 + (1-\alpha)|\beta_j|\right)$$

Tuning parameters $\alpha \in [0,1]$ and $\lambda \geq 0$ are determined by trialling different values to determine the combination which gives the optimal performance. $\alpha = 0$ is the ridge penalty; $\alpha = 1$ is the lasso penalty, and in between is a combination of the two. Prior to minimisation the response is centred (y_i sum to 0) and the predictors standardised (for each predictor variable j, $\sum_i x_{ij} = 0$ and $\sum_i x_{ij}^2 = 1$).

Predictor variables and regression formula

Three different formulas were tested for the elastic net regression (and the same were used for the extreme gradient boosting). Using the notation from above,

$y =$ daily energy consumption (kWh)

Formula f_1:

132 Overfitting is when a model fails to generalise to new data because it has become too closely aligned to training data and missed the general trends.

133 Zou, H. and Hastie, T. (2005). Regularization and variable selection via the elastic net. *J. R. Statist. Soc. B*. **67**(2), pp301-320.

134 Sâtre-Meloy, A. (2019). Investigating structural and occupant drivers of annual residential electricity consumption using regularization in regression models, *Energy*, **174** p148-168.

$$\sum_{j=1}^{p} \beta_j x_j = \beta_1 \text{sin\_day} + \beta_2 \text{cos\_day} + \beta_3 \text{weekend or holiday indicator}$$
$$+ \beta_4 \text{mean temperature at 2m above surface level}$$
$$+ \beta_5 \text{minimum temperature at 2m above surface level}$$
$$+ \beta_6 \text{maximum temperature at 2m above surface level}$$
$$+ \beta_7 \text{mean temperature at 2m above surface level on previous day}$$
$$+ \beta_8 \text{mean solar radiation} + \beta_9 \text{mean solar radiation on previous day}$$
$$+ \beta_{10} \text{total precipitation} + \beta_{11} \text{mean wind speed} + \beta_{12} \text{maximum wind speed}$$

Formula f_2

$$\sum_{j=1}^{p} \beta_j x_{ij} = \beta_1 \text{sin}_{\text{day}} + \beta_2 \text{cos}_{\text{day}} + \beta_3 \text{weekend or holiday indicator}$$
$$+ \text{weekend or holiday indicator}$$
$$\times (\beta_4 \text{mean temperature at 2m above surface level}$$
$$+ \beta_5 \text{minimum temperature at 2m above surface level}$$
$$+ \beta_6 \text{maximum temperature at 2m above surface level}$$
$$+ \beta_7 \text{mean temperature at 2m above surface level on previous day}$$
$$+ \beta_8 \text{mean solar radiation} + \beta_9 \text{mean solar radiation on previous day}$$
$$+ \beta_{10} \text{total precipitation} + \beta_{11} \text{mean wind speed} + \beta_{12} \text{maximum wind speed})$$

Formula f_3

$$\sum_{j=1}^{p} \beta_j x_{ij} = \beta_1 \text{sin}_{\text{day}} + \beta_2 \text{cos}_{\text{day}} + \beta_3 \text{weekend or holiday indicator}$$
$$+ \beta_4 \text{mean temperature at 2m above surface level}$$
$$+ \beta_5 \text{minimum temperature at 2m above surface level} + \beta_8 \text{mean solar radiation}$$
$$+ \beta_{10} \text{total precipitation} + \beta_{11} \text{mean wind speed} + \beta_{12} \text{maximum wind speed}$$
$$+ \text{weekend or holiday indicator}$$
$$\times (\beta_4 \text{mean temperature at 2m above surface level}$$
$$+ \beta_5 \text{minimum temperature at 2m above surface level}$$
$$+ \beta_6 \text{maximum temperature at 2m above surface level}$$
$$+ \beta_7 \text{mean temperature at 2m above surface level on previous day}$$
$$+ \beta_8 \text{mean solar radiation} + \beta_9 \text{mean solar radiation on previous day}$$
$$+ \beta_{10} \text{total precipitation} + \beta_{11} \text{mean wind speed} + \beta_{12} \text{maximum wind speed})$$

Recall that the elastic net regression eliminates inconsequential variables by penalising an excess number of predictor variables, therefore the optimized models may not include all of the variables in the formula. The interaction with the weekend/holiday variable allows a household to respond differently to weather conditions if it is a weekend or holiday day (combined due to the low number of bank holidays in the training period). For example, you may go to work on weekdays irrespective of the cold, but at the weekend you might choose to stay inside and keep warm. Or when it is hot to do the washing so it can dry outside, but only if you're home (more likely at the weekend). Each household has its own model so they can have different variables and relationships between the variables from one another.

Performing elastic net regression in R

Elastic net regression was performed using the caret[135] and glmnet[136] packages in R. 10 values for each of tuning parameters α and λ were tested (i.e. tune length 10) using the caret function 'train' and 5-fold cross-validation. The best-performing tuning parameters were then selected to train the predictive model using the full set of training data (October 2021 – March 2022).

Linear Regression

A linear regression model was also included in the model selection process. This is a standard ordinary least squares (OLS) linear regression model. It is therefore identical to the elastic net regression minus the elastic net penalty term. Using the notation from above the formula used was Formula f_4:

$$
\begin{aligned}
\sum_{j=1}^{p} \beta_j x_j = \; & \beta_1 \sin_{\text{day}} + \; \beta_2 \cos_{\text{day}} + \beta_3 \text{weekend indicator} + \beta_4 \text{holiday indicator} \\
& + \; \beta_5 \text{mean temperature at 2m above surface level} \\
& + \beta_6 \text{mean temperature at 2m above surface level on previous day (minus 1)} \\
& + \; \beta_7 \text{mean temperature at 2m above surface level on previous day (minus 2)} \\
& + \beta_8 \text{mean temperature at 2m above surface level on previous day (minus 3)} \\
& + +\beta_9 \text{mean solar radiation} \\
& + \beta_{10} \text{mean solar radiation on previous day (minus 1)} \\
& + \beta_{11} \text{mean solar radiation on previous day (minus 2)} \\
& + \beta_{12} \text{mean solar radiation on previous day (minus 3)} + \quad \beta_{13} \text{total precipitation} \\
& + \beta_{14} \text{mean wind speed} + \; \beta_{15} \text{maximum wind speed}
\end{aligned}
$$

Neural network

Introduction

Similar to the elastic net regression model described above, a neural network (or 'artificial neural network') is a type of model that is used to estimate a function that describes the relationship between a set of input variables and one or more output variables. In this case

135 Kuhn, M (2021). Caret: Classification and Regression Training. https://CRAN.R-project.org/package=caret

136 Friedman, J., Hastie, T., Tibshirani, R. (2010). Regularization Paths for Generalized Linear Models via Coordinate Descent. Journal of Statistical Software, 33(1), 1-22. https://www.jstatsoft.org/v33/i01/

the inputs are calendar and weather variables, and the output is daily electricity or gas consumption for an individual household.

A neural network consists of a network of multiple ‘neurons’ or ‘units’ which are connected in ‘hidden’ layers so that the outputs of the units in one layer are used as inputs to the units in the next layer. This is known as a ‘feedforward neural network’. Each unit is represented by an equation similar to the elastic net regression equation: a linear sum of the inputs multiplied by parameters known as weights and a bias term. The output of this equation is then passed through an ‘activation function’ which is usually a non-linear function. A neural network can consist of many such units and the benefit of this is that they can estimate highly non-linear relationships between input and output variables. This is a strength of neural networks compared to a simpler model such as the elastic net regression model described previously and a reason why we choose this type of model to complement it.

Input variables

The neural network used the same input variables as used in the linear regression model (formula f_4 above) with min-max scaling for the sinusoidal calendar variables and standard scaling for all other continuous variables.

Cross-validation

5-fold cross-validation was used to calculate the trained models out-of-sample error and to select the best performing model hyper-parameters.

Model hyper-parameters

Six combinations of hyperparameters were trained. Three choices of hidden layer structure:

- 2 hidden layers of 2 units
- 2 hidden layers of 3 units
- 2 hidden layers of 4 units

And two values of alpha (a regularising parameter similar to that used in the elastic net regression to mitigate model over-fitting): 0.0001 and 0.1. The hyperparameter combination that resulted in the lowest out of sample error from the cross validation was selected. Relu activation functions were used.

Training

The cost function used was the mean squared error of the model output compared to the target observations.

The cost function was minimised using the ‘adam’ solver with a maximum number of iterations of 1500.

For each participant the cross-validation predictions for the best performing set of hyperparameters are combined to produce a single file for the training period which contains the out-of-sample predictions for the 5 cross-validation models. This file is used to estimate the out-of-sample error / model performance for each participant and fuel.

Prediction

For each participant, then a final single model using the best set of hyperparameters is trained on the full training data. This final model is then used to create counterfactual predictions during the prediction period using input data from the prediction period. These final predictions can be compared to the actual observations during the prediction period to estimate the change in electricity or gas demand.

Hardware and software

All analysis was performed in the UCL Data Safe Haven. Programming was implemented using python 3.8.5 using pandas 1.5.3, numpy 1.23.5, and scikit-learn 1.2.2.

Extreme gradient boosting

Introduction

Extreme gradient boosting is an 'ensemble method'; the result of combining multiple models and taking the best attributes of each. 'Boosting' is the name of an iterative learning process that starts with an initial (base) model and builds up the ensemble by training multiple models by re-weighting the dataset to favour harder-to-predict data points in later model runs. The final model is found by averaging over the ensemble of models[137] [138]. Extreme gradient boosting ('XGBoost') is a popular type of scalable boosting technique which improves upon gradient boosting in terms of computational efficiency and in combatting over-fitting[139], with notable success in machine learning competitions[140]. The simplest type is to use a linear base model, which is a natural extension of elastic net regression, and that is the type we use here, having previously shown excellent performance in predicting domestic energy demand[141]. Due to the longer run time than the other models, we only tested formulas f_1 and f_3.

137 T. Hastie, R. Tibshirani, and J. Friedman, The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Second. Springer-Verlag, 2009. [Online]. Available: https://hastie.su.domains/Papers/ESLII.pdf

138 C. Wade, Hands-On Gradient Boosting with XGBoost and scikit-learn: Perform accessible machine learning and extreme gradient boosting with Python. Packt Publishing Ltd, 2020.

139 T. Chen and C. Guestrin, "XGBoost: A scalable tree boosting system," Proc. ACM SIGKDD Int. Conf. Knowl. Discov. Data Min., vol. 13-17-Augu, pp. 785–794, 2016, doi: 10.1145/2939672.2939785

140 D. Nielson, "Tree Boosting with XGBoost: Why Does XGBoost Win 'Every' Machine Learning Competition?," Norwegian University of Science and Technology, 2016. doi: 10.1111/j.1758-5899.2011.00096.x.

141 Zapata-Webborn, Ellen, Martin Pullinger, Eoghan J. McKenna, Callum Cheshire, Harry Masters, Alex Whittaker, Jessica Few, et al. 2023. "The Short- and Long-term Impacts of COVID-19 on Household Energy Consumption in England and Wales." OSF Preprints. March 21. doi:10.31219/osf.io/m5p3b

Performing extreme gradient boosting in R

We performed XGBoost using the R package xgboost[142] implemented with caret[143] and a linear booster gblinear. We used 100 rounds, step size η=0.1 and tested α and λ in {0, 0.25, 0.5, 0.75, 1}.

Negative predictions

In some instances (particularly for gas) the models predicted negative consumption. Where this occurred, all negative predictions were replaced by zero, in both the training and prediction period (i.e. the cross-validations used this process too in order that the error and bias would be reflective of the processes used).

Model selection and evaluation

For each household several models of each type of algorithm were tried to determine which was most suited for electricity use prediction. Model parameters were tuned using 5-fold cross-validation and the optimal parameters selected for predictions. Data from the previous winter was used for training and testing which gives estimates for the error and bias of each model with the selected parameters. To compare, for example, a neural network model with an elastic net regression model we can compare the error and bias of these models from the cross-validation process.

Error is a measure of how accurate the model is in predicting the observed values; the smaller the error, the greater the accuracy. Bias is a measure of systematic over- or under-prediction of the observed values. During model selection and evaluation both error and bias were considered, as model accuracy is important, but an accurate model that, say, over-predicts demand at certain times of the day or months of the year could lead to results that appear to be significant that are not, or trends hidden by systematic bias in the predictions.

We considered the coefficient of variation of the root mean squared error CV(RMSE) as our error metric and normalised mean bias error (NMBE) for bias, defined as follows:

$$\text{NMBE} = \frac{1}{\mathrm{n}-1}\frac{\sum(\hat{y}_{\mathrm{i}} - \mathrm{y_i})}{\bar{\mathrm{y}}}$$

$$\text{CV(RMSE)} = \frac{1}{\bar{y}}\sqrt{\frac{\sum(y_i - \hat{y}_i)^2}{n-1}}$$

[142] T. Chen et al., “xgboost: Extreme Gradient Boosting.” 2022. [Online]. Available: https://cran.r-project.org/package=xgboost

[143] Kuhn, M (2021). Caret: Classification and Regression Training. https://CRAN.R-project.org/package=caret

Where n is the number of observations, y_i is the i^{th} observation, $\hat{y}_i$ is the i^{th} prediction, and $\bar{y}$ is the mean of the observations. NMBE > 0 means the model tends to over-predict.

To select the optimal model for each household, first any models with NMBE > 5% were eliminated, and then for each household, the model with the lowest CV(RMSE) was selected. Any final models with CV(RMSE) > 15% were removed (i.e. the household was discarded from the sample)[144].

Following this process the numbers of each model selected were:

Table 9 Numbers of each selected model

Model type	Formula	Number	Total
		Electricity	
Elastic net regression	F_1	296	7,415
Elastic net regression	F_2	96	
Elastic net regression	F_3	202	
Neural network	F_4	26	
Linear regression	F_4	465	
XGBoost	F_1	2,994	
XGBoost	F_3	3,336	
		Gas	
Elastic net regression	F_1	287	6,878
Elastic net regression	F_2	137	
Elastic net regression	F_3	406	
Neural network	F_4	1	

144 Our thresholds are taken from the ASHRAE guidelines (ASHRAE) American Society of Heating, Ventilating, and Air Conditioning Engineers, "Guideline 14-2014, Measurement of Energy and Demand Savings," Atlanta, GA, 2002. [Online]. Available: http://www.eeperformance.org/uploads/8/6/5/0/8650231/ashrae_guideline_14-2002_measurement_of_energy_and_demand_saving.pdf

Model type	Formula	Number	Total
Linear regression	F_4	719	
XGBoost	F_1	2326	
XGBoost	F_3	3002	

Source: UCL analysis

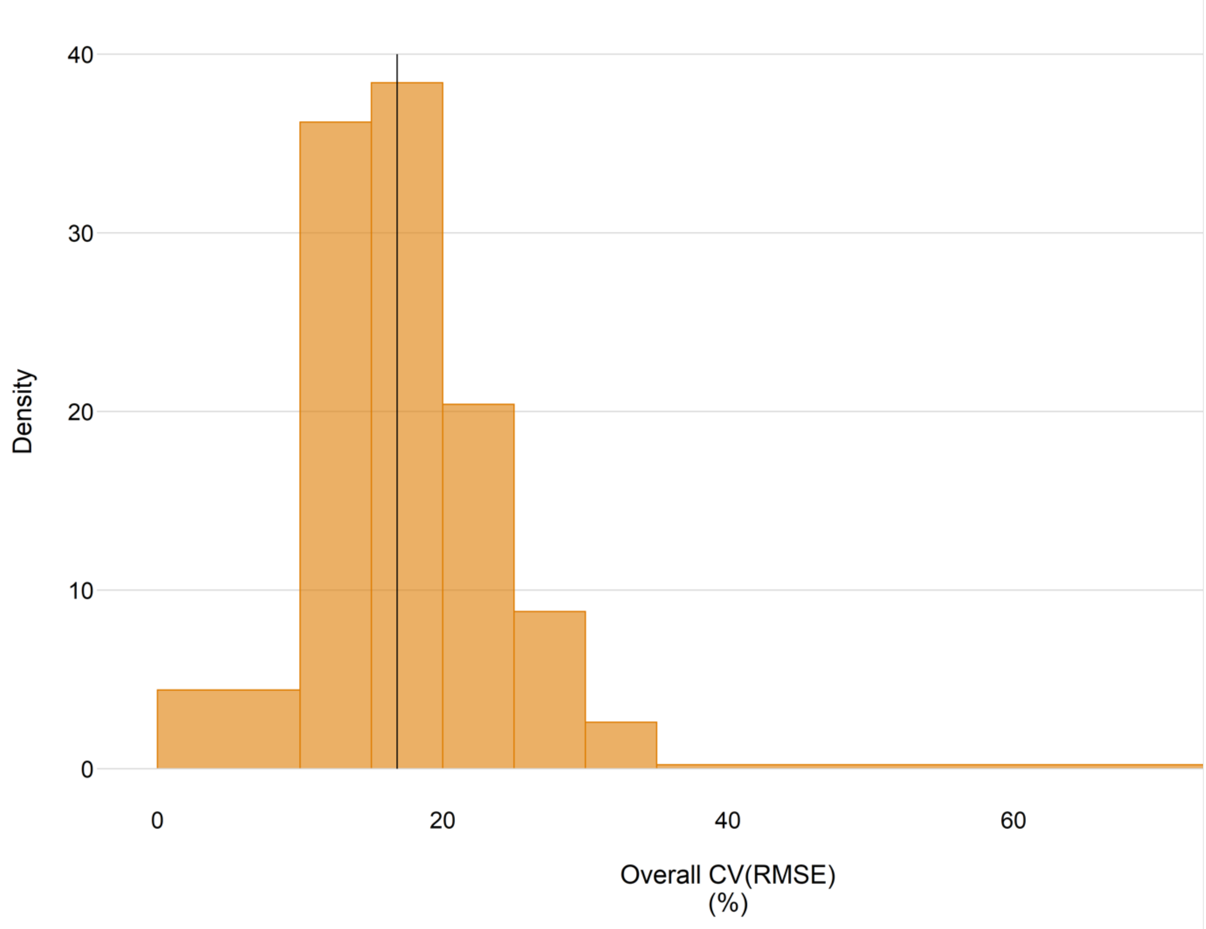
Final model error and bias

In this section we explore the error and bias of the final household models for electricity and gas.

Overall error and bias

Due to our error and bias tolerance thresholds all model errors are less than 15% (CV(RMSE) at a monthly level) and model bias between -5% – 5% (NMBE at a monthly level). At a sample level, mean error was 3.16% for electricity and 3.33% for gas models; mean bias was 0.53% for electricity and 0.56% for gas homes.

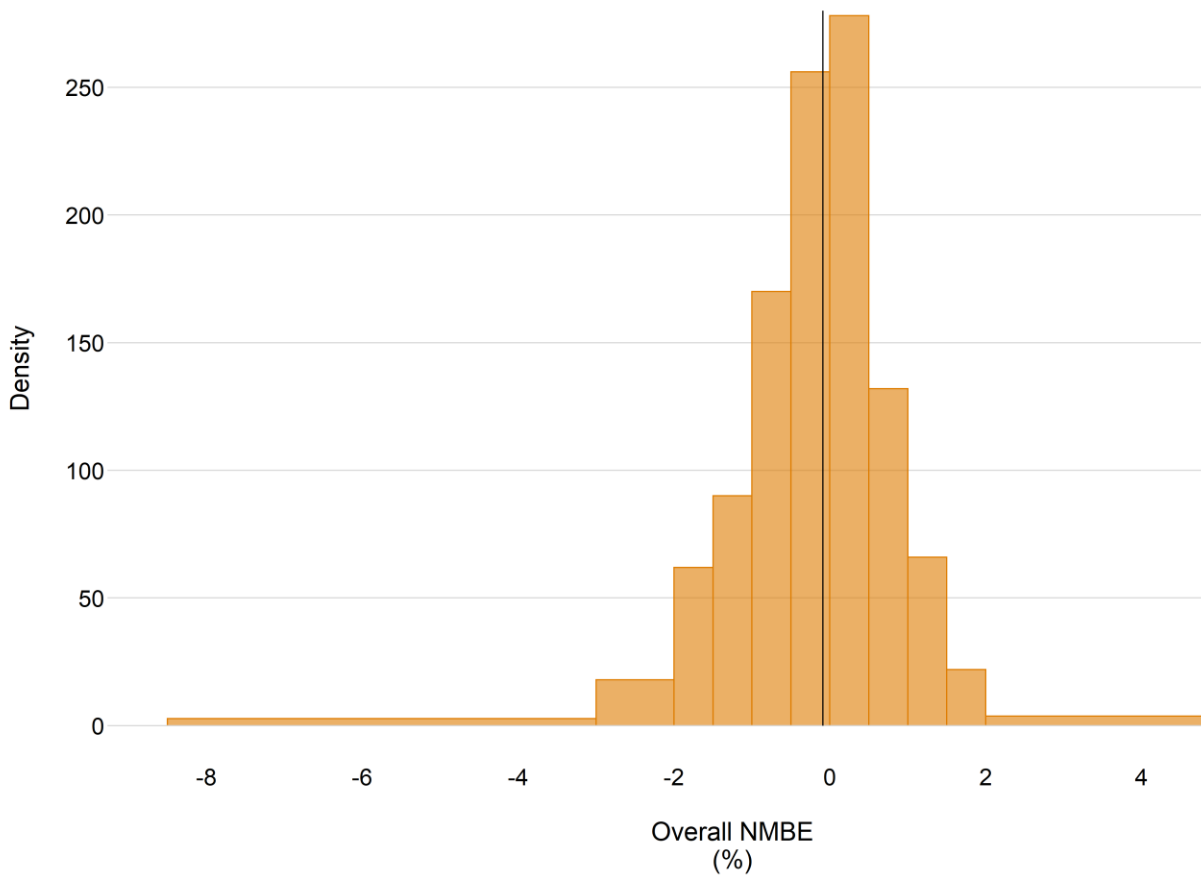
Figure 37 Overall error for the COVID-19 sample



Source: UCL analysis using SERL data
Note: Black line indicates an approximation of the median; 16.8%.

The same source recommends NMBE within ±5% or 10% at an hourly resolution (NMBE within ±5% or 20% depending on the standard at a monthly resolution). The figure below shows overall bias well within these ranges for almost all households, and overall (median) bias extremely close to zero at less than 0.09%

Figure 38 Overall model bias for the population



Source: UCL analysis using SERL data
Note: Black line indicates an approximation of the median; -0.0892%.

B.4 Considerations when using and interpreting model outputs and results

We have endeavoured to make the model predictions as accurate as possible by testing several models, modelling each house individually, and requiring 6 months of historic data from the previous winter for training and testing. Cross-validation allowed us to perform model analysis of error and bias, and models with high error or bias were excluded. We found that for most households model bias was very low, and model error was fairly low. However, there are a number of weaknesses that should be considered when working with the models and interpreting any results.

- Naturally some households were more predictable than others, likely due to household behavioural patterns and amount of data available. Some households suffered from much higher model error than others, and so it is best not to consider any household in isolation when comparing predictions with observations. The larger the group of households considered, the more confident we can be in our predictions.

- Some changes should be expected for some of the households between this and last winter. For example, a change in the number of occupants, appliance purchases, and changes to the dwelling. Our model is unable to take these into account (although where survey data informs us of such changes between winters, we are able to exclude such households from analysis).

- The samples are relatively large for energy studies, and contains households from England, Wales and Scotland. However, there will be ways in which it is not representative of the national population, which should be taken into account when generalising from the results.

Despite the weaknesses mentioned above, the longitudinal data supported by detailed survey data has allowed us to create valuable predictive models that offer greater predictive power than is commonly done in other studies and offer insights into how the cost-of-living crisis has affected the electricity consumption of households in Great Britain.

Annex C – Sample representativeness

In principle there are two possible sources of bias in our sample of households. When households are recruited to the SERL Observatory, there could be some households with certain characteristics that are more likely to agree to the required data-sharing conditions than others (therefore creating a ‘participation bias’). There are two papers that describe and explore the data in more detail and consider representativeness and find limited participation bias in the overall sample.[145][146] In addition, the survey could have a ‘response bias’, with some households with certain characteristics that are more likely to respond than others. This means our sample of survey respondents may contain some response bias. We are able to check whether this is the case by comparing sample average against population averages for different characteristics.[147]

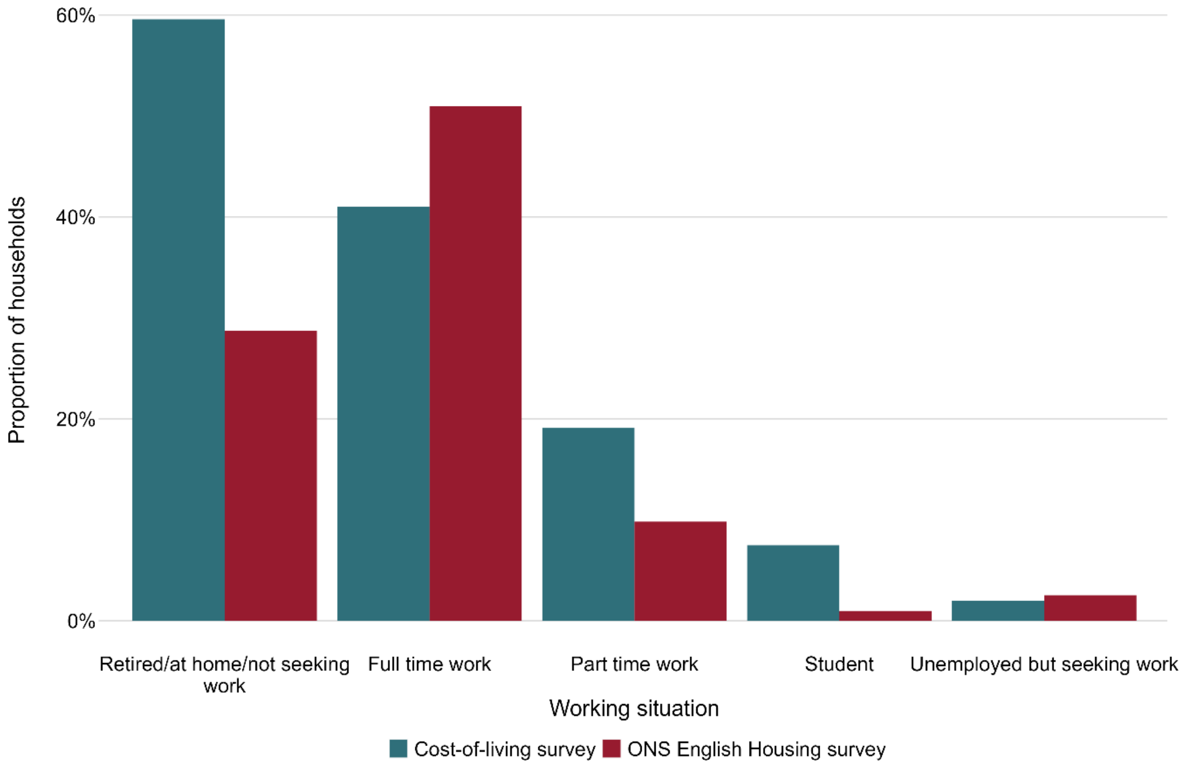
Our survey asks respondents to describe the working situation of each occupant aged 16 and above. To do so, they are asked to indicate how many occupants would fall into each of a set of categories: working (at least 30 hours a week), working (less than 30 hours a week), not working because of long term sickness or disability, unemployed, student, retired/at home/not seeking work and other. In Figure 39, we compare the proportion of households that contain at least one person for each of the categories against the household reference person of the Office for National Statistics English Housing Survey.

145 Webborn, E., McKenna, E., Elam, S., Anderson, B., Cooper, A. and Oreszczyn, T., 2022. Increasing response rates and improving research design: Learnings from the Smart Energy Research Lab in the United Kingdom. *Energy Research & Social Science*, 83, p.102312.

146 Webborn, E., Few, J., McKenna, E., Elam, S., Pullinger, M., Anderson, B., Shipworth, D. and Oreszczyn, T., 2021. The SERL Observatory Dataset: Longitudinal smart meter electricity and gas data, survey, EPC and climate data for over 13,000 households in Great Britain. *Energies*, 14(21), p.6934.

147 Bias, in the context of surveys, refers to the sample of survey respondents being unrepresentative of the population.

Figure 39 Working situation of households in the SERL cost-of-living survey compared to the ONS English Housing survey



Source: Frontier Economics analysis of SERL survey data; ONS English Housing survey

Just over 40% of households in the cost-of living survey have at least one member that is working full time (‘30 hours a week or more’), whilst 51% of the household reference persons in the English Housing survey are full time workers. [148] In addition, there are almost a fifth of households with at least one member working part time (‘less than 30 hours a week’) in the cost-of living survey, but only 9.8% of the household reference persons in the English Housing survey are part time workers. The differences between the two surveys could be due to different definitions of part- and full-time work.[149] If we aggregate full time and part time work, the values are 60% for the cost-of-living survey, and 61% for the English Housing survey.

Almost 60% of households in the cost-of-living survey have at least one retiree, whereas only 28% of the household reference persons in the English Housing survey are retirees. One reason could be the wider definition in the cost-of-living survey, which also includes those not

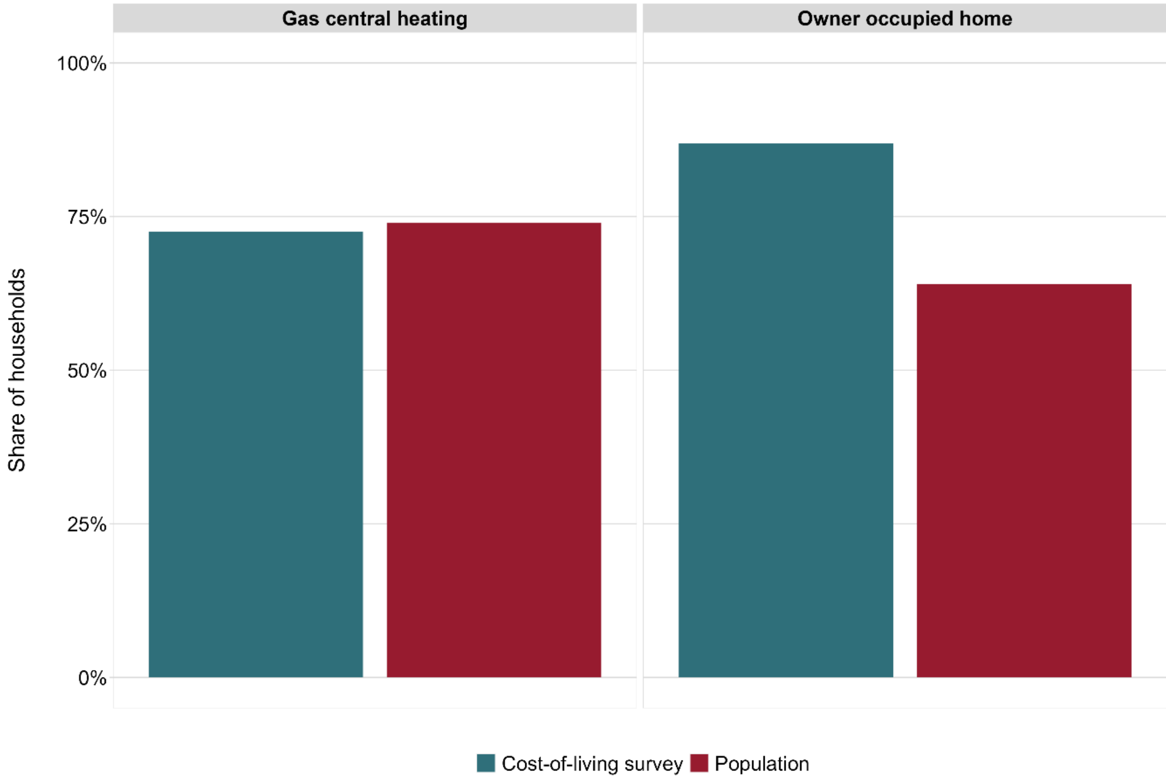
148 ONS. 15 December 2022. *English Housing Survey 2021 to 2022 headline report.*

149 The cost-of-living survey asks households whether there is at least one person working more than 30 hours per week, and at least one person working less than 30 hours per week, which we categorise as full-time and part-time, respectively. On the other hand, the English Housing survey refers to ‘full-time’ and ‘part-time’ work, and the annex tables containing the data don’t state the definition.

seeking work (amongst ONS household reference people, 7% were economically inactive for other reasons). In addition, it should be noted that the surveys are not directly comparable, as the ONS survey captures only one household member whilst our survey captures each person in the household.

In Figure 40 we consider how the proportion of households in owner-occupied homes and the proportion of households with gas central heating compare to the population.

Figure 40 Gas central heating and owner-occupied home comparison between the cost-of-living survey and the population



Source: Frontier Economics analysis of SERL survey data; ONS, Subnational estimates of dwellings and households by tenure, England: 2020; ONS, 2021 Census, Dataset TS046; Commons Library calculations

We can see that on the population level (which in this case refers to England), the proportion of owner-occupied housing is around 64%.[150] The survey sample estimates the proportion of owner-occupied homes as 87%. Therefore our survey sample might overrepresent owner occupied housing. However when considering the proportion of households with gas central heating, the population statistic is 74% and the survey suggests a similar proportion.[151]

[150] ONS, Subnational estimates of dwellings and households by tenure, England: 2020

[151] ONS, 2021 Census, Dataset TS046; Commons Library calculations

Sample conclusions

We have described some characteristics of the sample of household sample, and we have also assessed the potential for bias in the household sample by comparing to population statistics.

On the question of bias, we can be reassured from previous studies that there is little participation bias in the wider sample. However on response bias, it is difficult to draw firm conclusions. Some household groups are clearly represented more in our survey sample than in the population. For example, there appears to be a greater proportion of retirees and individuals that work from home in our sample, as well as a greater number of owner-occupied households. It is possible that our survey overrepresents household groups that tend to stay at home more (and are more able to answer a survey) and therefore might exhibit different energy-saving behaviour to the population. This also means that households with less time and at home less are less able to answer a survey. This might exclude customers that are most vulnerable and may understate the extent to which our analysis captures the impact on fuel poverty.

However we have chosen not to re-weight our sample in line with the population averages. This is because there is significant variation in consumption changes within each of our household groups. This variation suggests some unobservable characteristic that tends to drive changes in consumption instead of our observable household groups. Therefore if we reweight towards some observable characteristics, we may overweight some unobservable characteristics (such as the tendency to be at home during the day).

Annex D – the impact of the cost-of-living crisis by household group

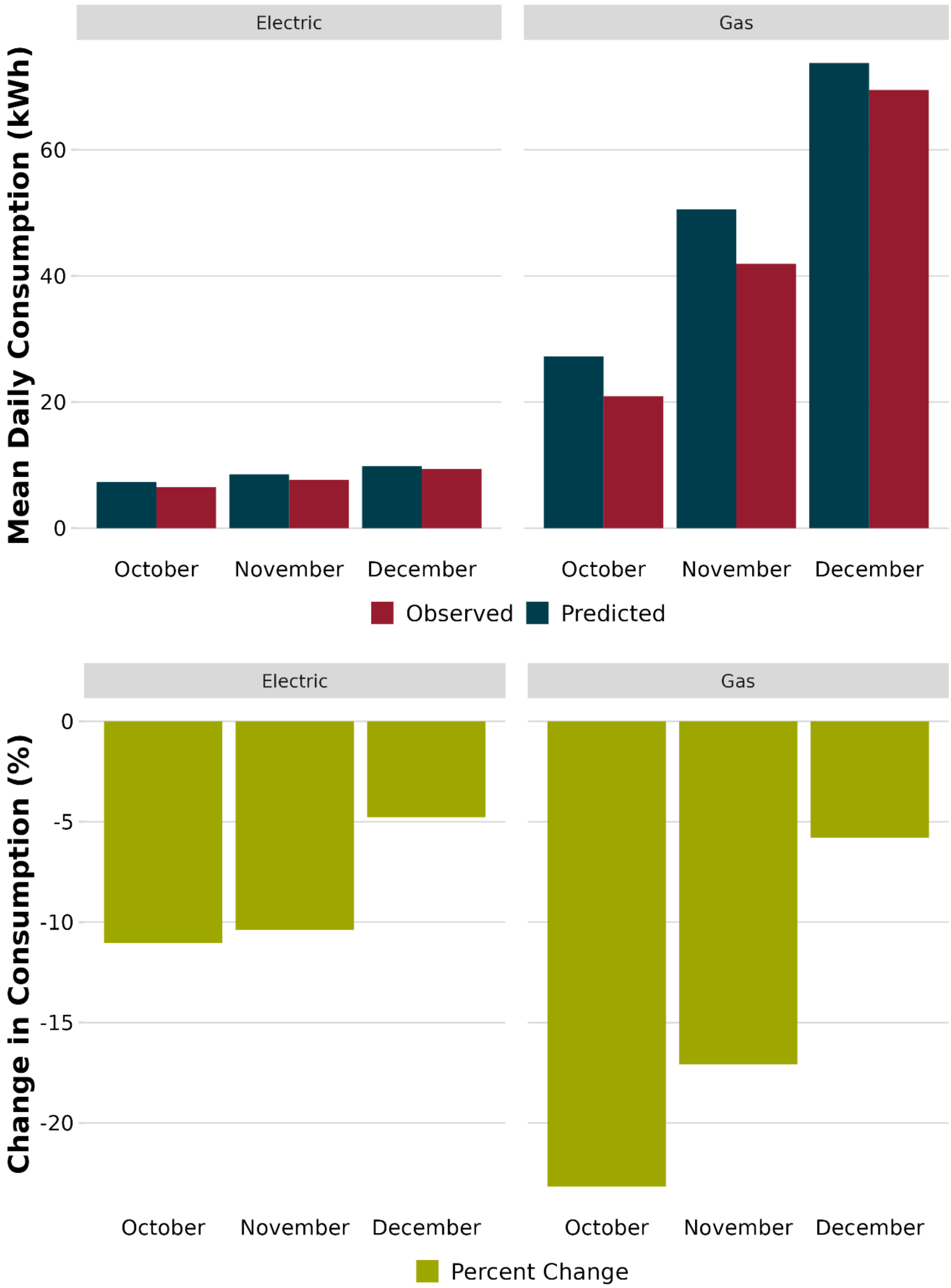
In this annex, we consider each of the households groups of interest (set out in 4.1). For each household group, we describe:

- The difference between observed and predicted consumption of electricity and gas over the winter period; and
- how being in or out of the household group affects the likelihood of households taking different actions.

D.1 Households with elderly members

Households with elderly members tend to have slightly lower electricity consumption and slightly higher gas consumption compared with average households across the whole period. However, both electricity and gas consumption decline more in the average household than in elderly households. In particular gas consumption falls by an average of 14% in all households but only 12.5% in elderly households. This is likely because elderly households prioritise keeping themselves warm over the winter.

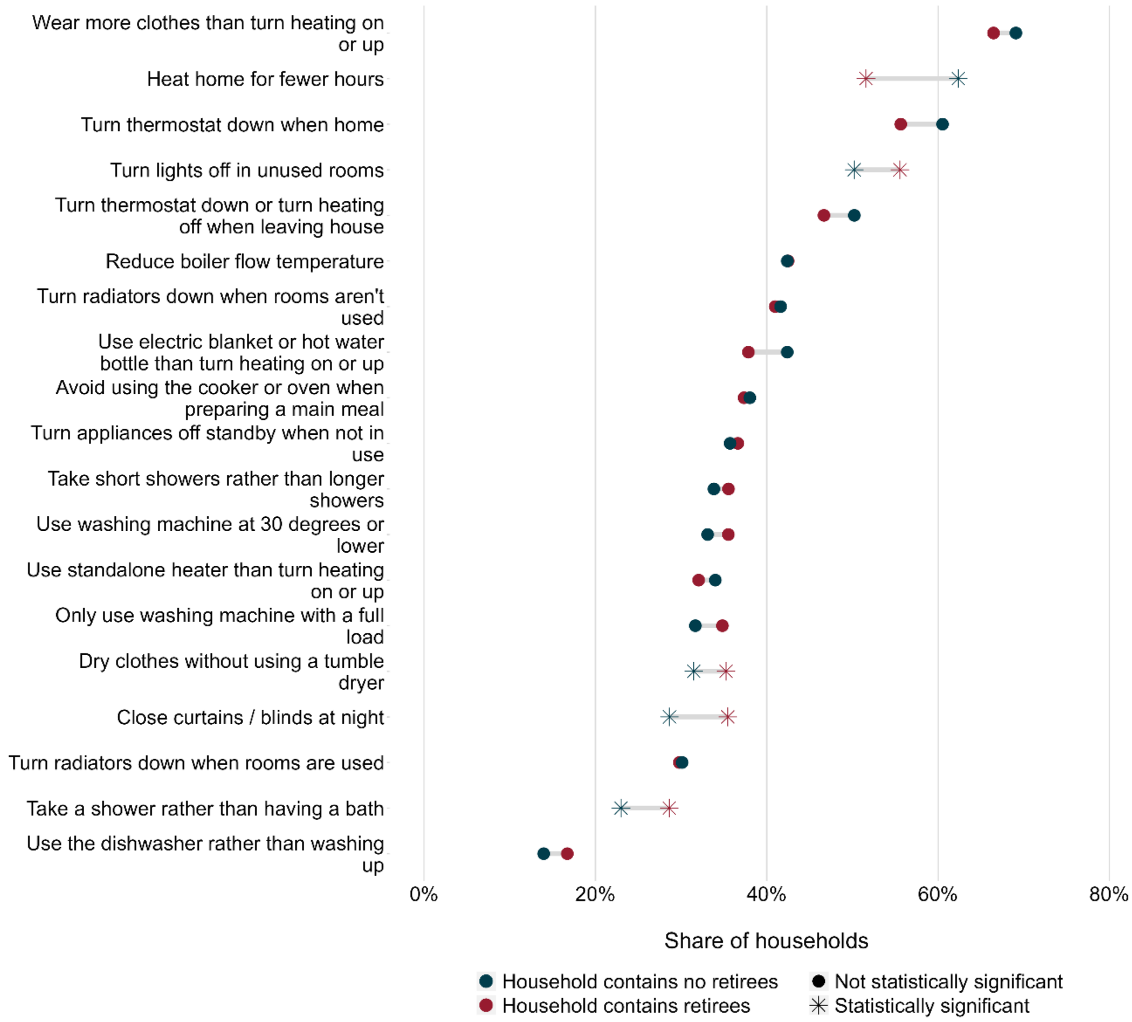
Figure 41 Impact of the cost-of-living crisis on energy consumption for households containing over 75s



Source: Frontier based on SERL data

Elderly households tend to take similar actions compared with all other households. In terms of actions that impact bills, they are less likely to heat their home for fewer hours. This suggests elderly households prioritise their comfort in their household. They also take some actions more frequently which have a smaller impact on bills.

Figure 42 Actions taken by households with elderly members compared to households without any elderly members



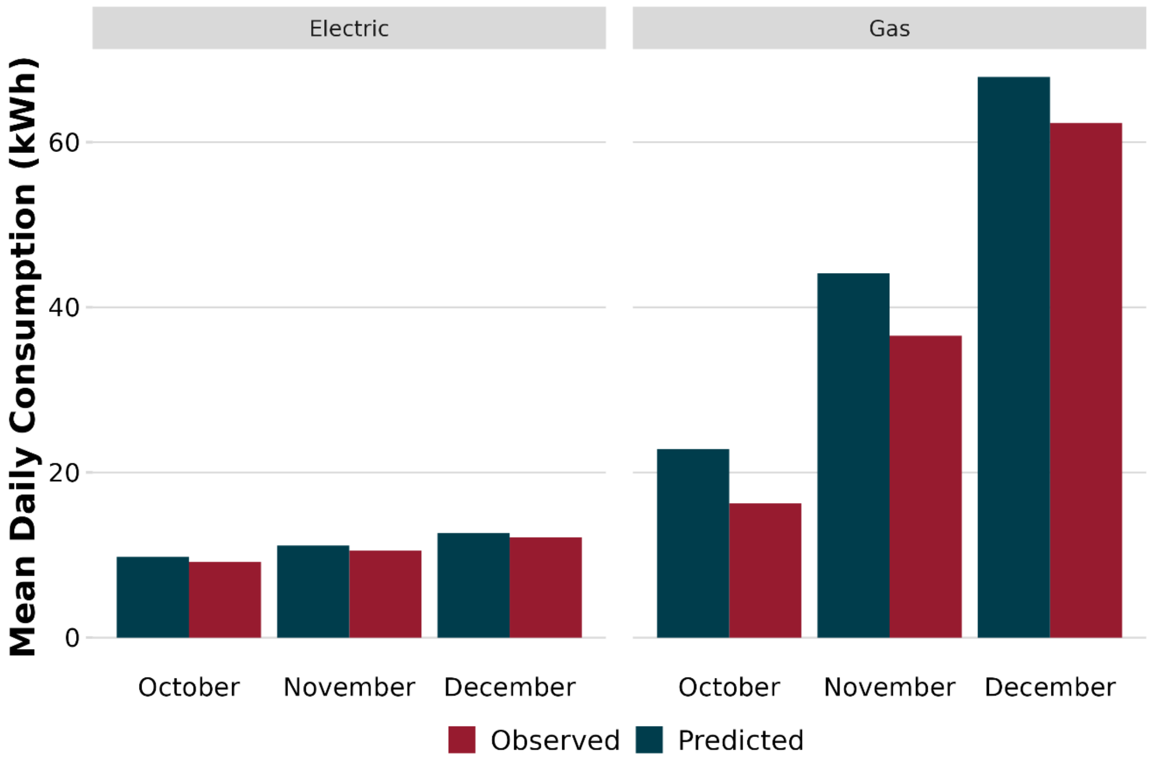
Source: Frontier Economics analysis of SERL data

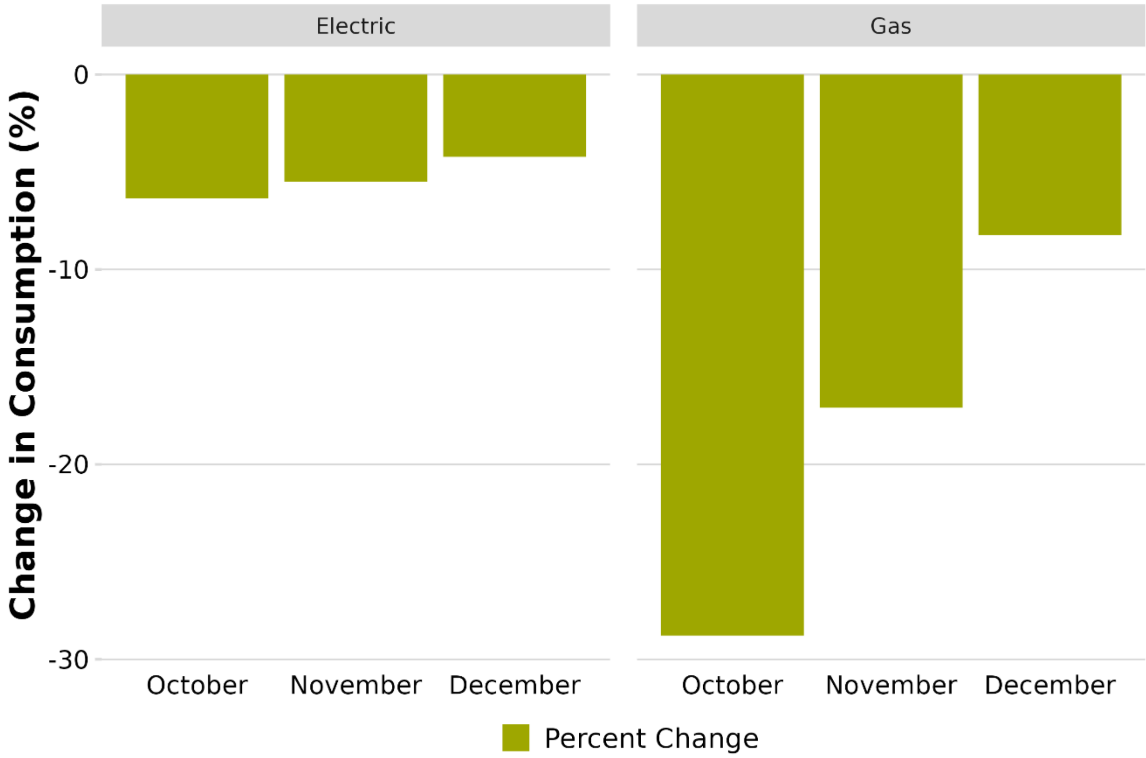
D.2 Households with young children

We consider households with young children. Figure 19 describes the actions taken for households with young children. The chart for households with young children suggests this household group is more likely to take energy-saving actions. However, the specific actions that this household group tends to take varies significantly. For example, households with young children are much more likely to use the washing machine at 30 degrees or lower. However they are less likely to avoid using the cooker or oven when preparing a main meal. Overall, Figure 19 refutes to some extent the hypothesis that households with young children have a greater propensity to maintain domestic energy expenditure, given that for most actions, they have a greater propensity to take energy-saving actions.

Households with young children tend to have higher electricity consumption and similar gas consumption compared with all households. Electricity consumption fell much less than consumption falls among all households across the whole winter (5% fall versus 8.5% fall in all households). Changes in consumption in October and November were much lower than for all households, showing less seasonal change in consumption, suggesting these households' electricity usage is more important. Changes in gas consumption were much more similar to all households.

Figure 43 Impact of the cost-of-living crisis on energy consumption for households with young children

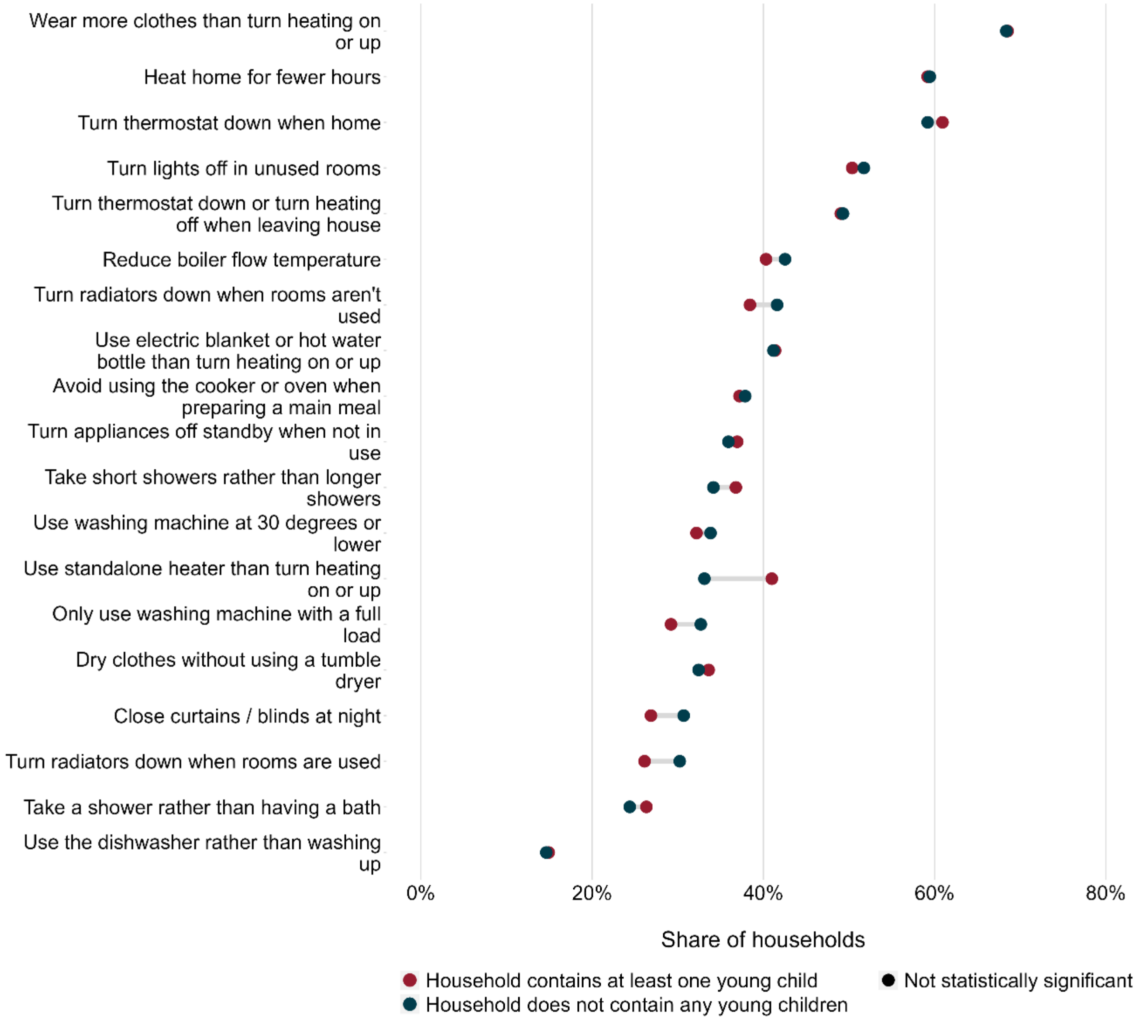




Source: Frontier Economics analysis of SERL data

However it is notable that, despite lower changes in electricity consumption, households with young children do not appear to be taking significantly fewer energy-saving actions (or significantly more compensatory actions). Greater use of standalone heaters is notable but not statistically significant.

Figure 44 Actions taken by households with young children compared to households without any young children

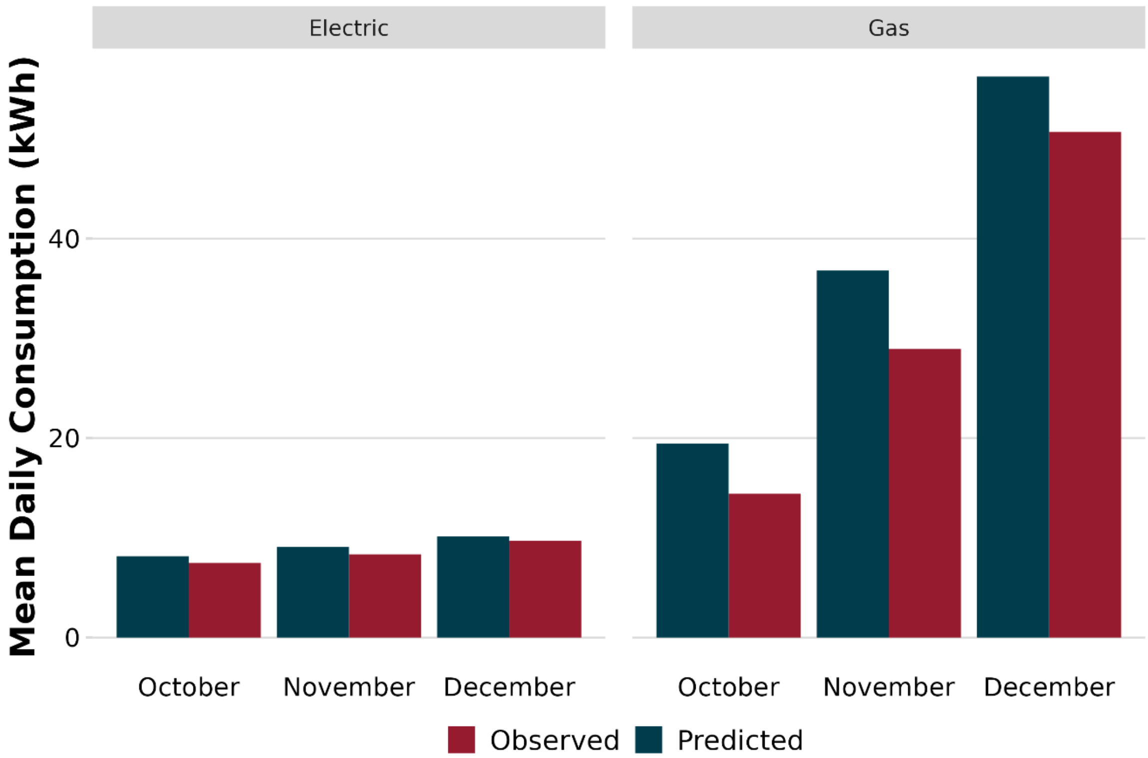


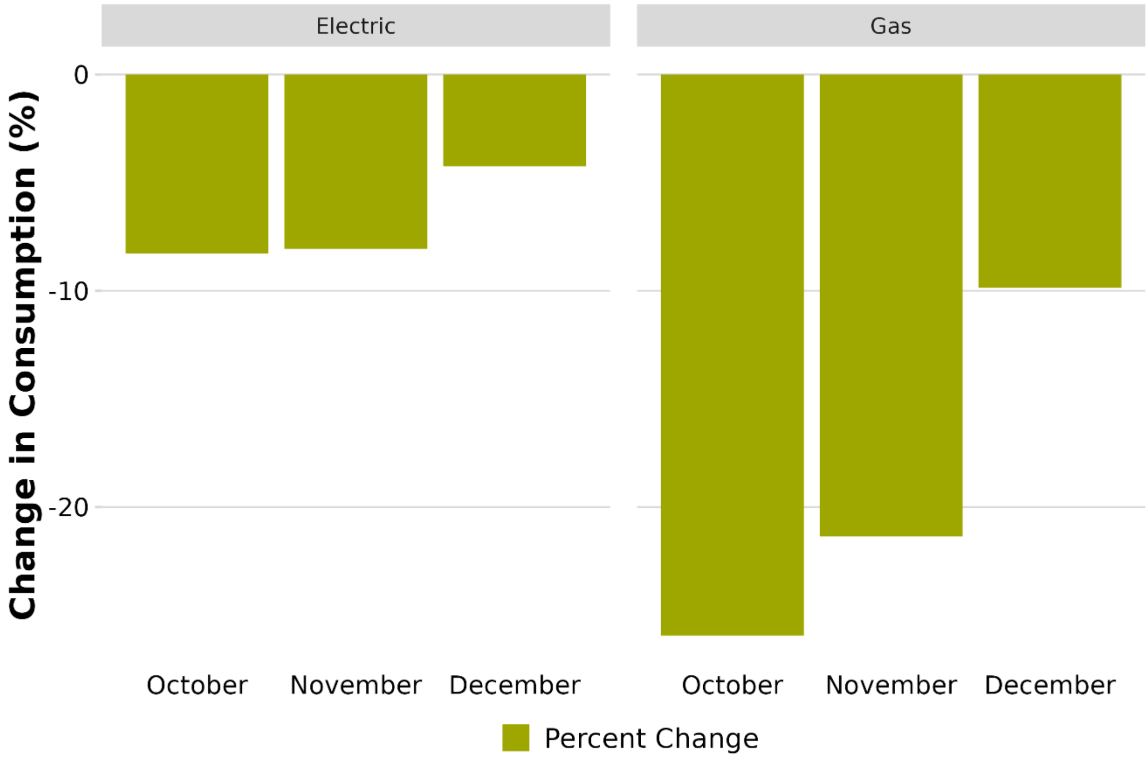
Source: Frontier Economics analysis of SERL data

D.3 Households with members not working due to long-term illness or disability

Households with ill or disabled members not working typically have higher electricity consumption but lower gas consumption compared to all households. However their change in electricity consumption was lower than average (maintaining their relatively high consumption) while their change in gas consumption was higher than average (decreasing their relatively low gas consumption. Particularly worrying is the gas consumption decreases in December of around 10%, which is much higher than the 6% average. This suggests that households with long-term illness or disability could be reducing heating consumption in homes that may already be underheated.

Figure 45 Impact of the cost-of-living crisis on energy consumption for households with people not working due to long-term illness or disability

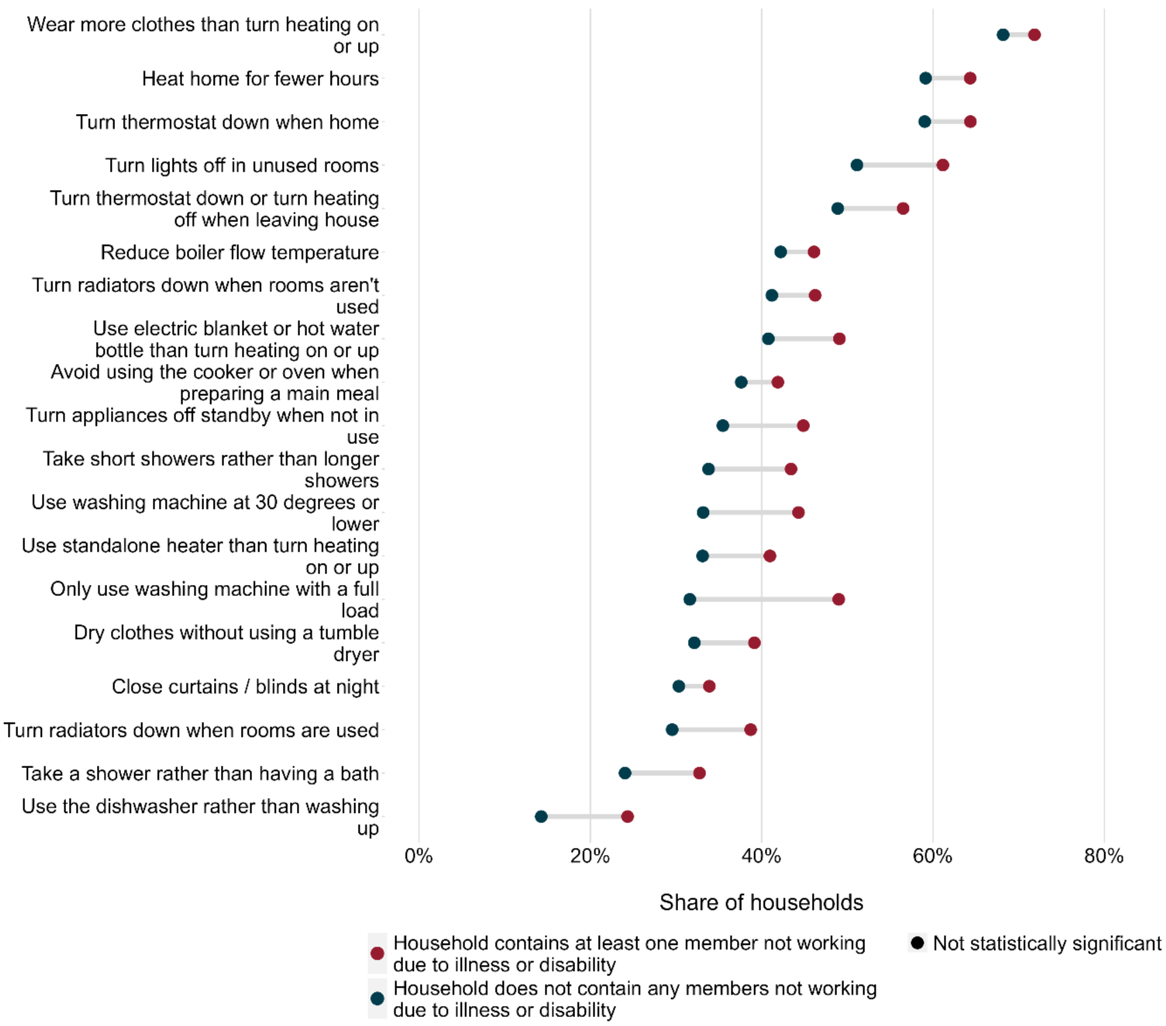




Source: Frontier Economics analysis of SERL data

Households with ill and disabled members tend to take more actions than other households but not significantly more than others.

Figure 46 Actions taken by households with ill / disabled members compared to households without any ill / disabled members

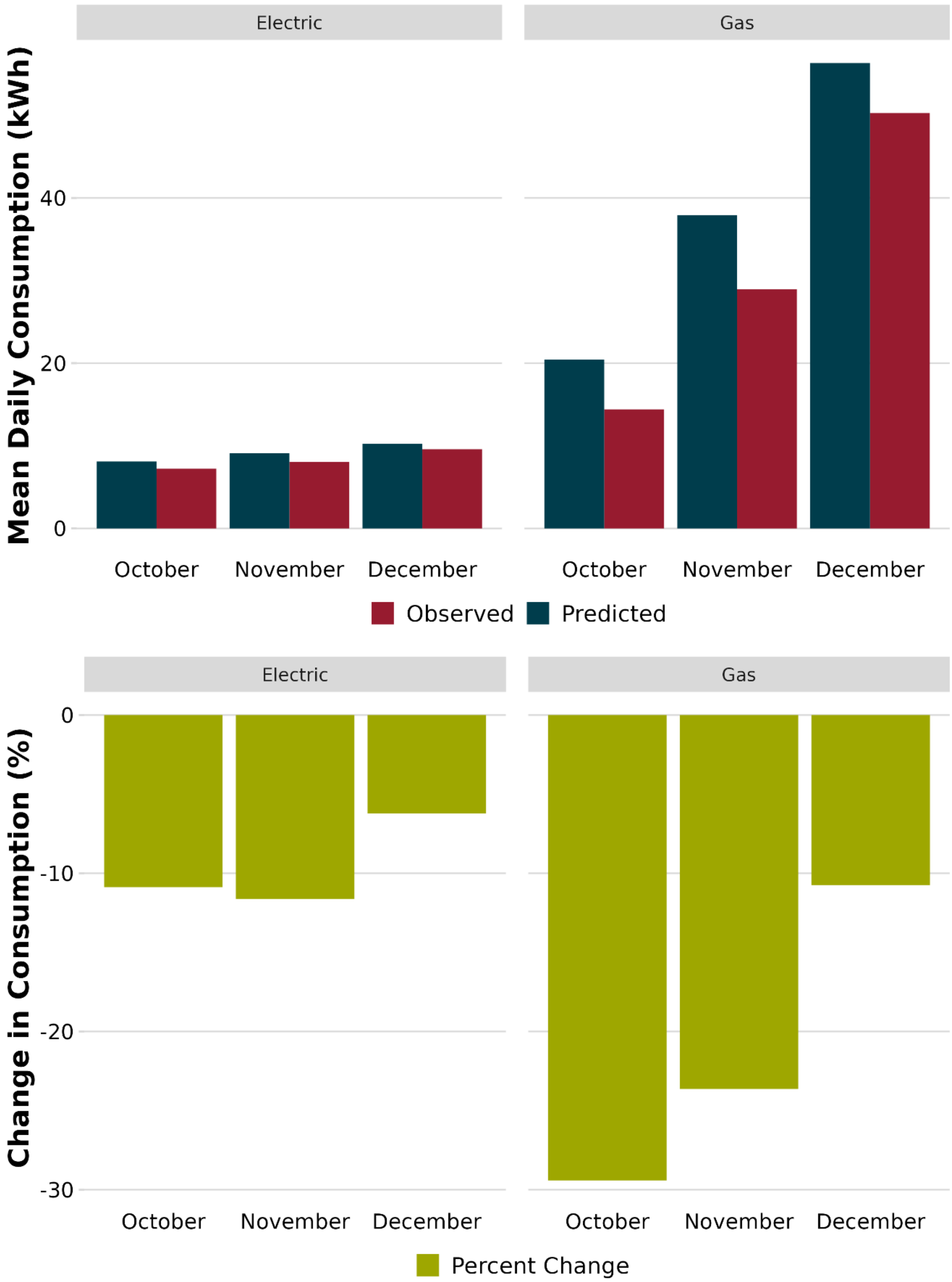


Source: Frontier Economics analysis of SERL data

D.4 Households that are 'financially struggling'

As discussed in Section 4, households that are 'financially struggling' have some of the biggest changes in consumption and typically take the most actions. These households tend to have very similar electricity consumption and much lower gas consumption than all households. The change in electricity consumption is larger than average households while the change in gas consumption is much larger than average household changes. The worrying finding is that households that are 'financially struggling' may be underheating their homes in advance of the cost-of-living crisis and then reducing consumption even further by a large amount, leading to cold homes.

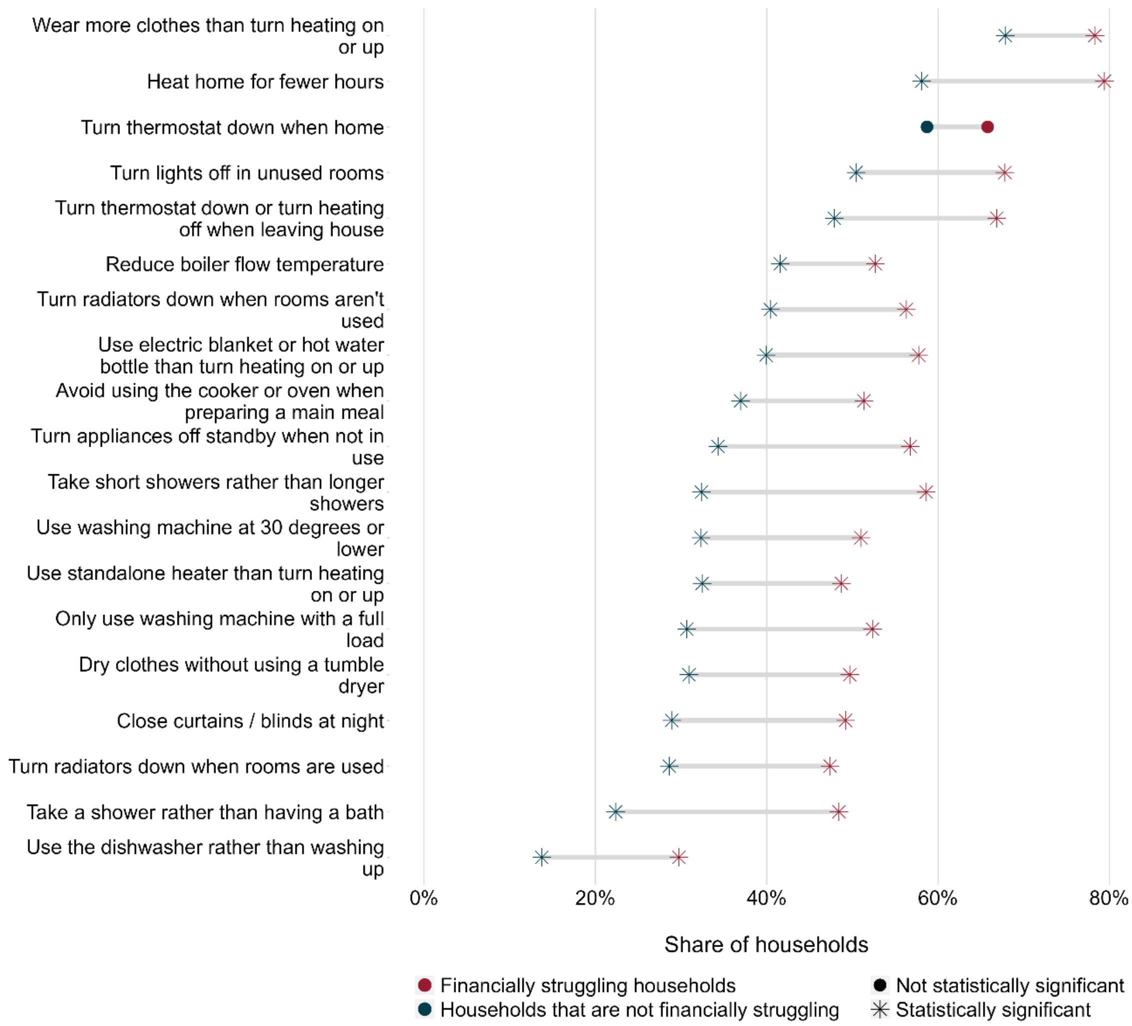
Figure 47 Impact of the cost-of-living crisis on energy consumption for households that are ‘financially struggling’



Source: Frontier Economics analysis of SERL data

The large fall in gas consumption is reflected by 'financially struggling' households more likely to take almost all actions than the average household.

Figure 48 Actions taken by 'financially struggling' households compared to households that aren't 'financially struggling'

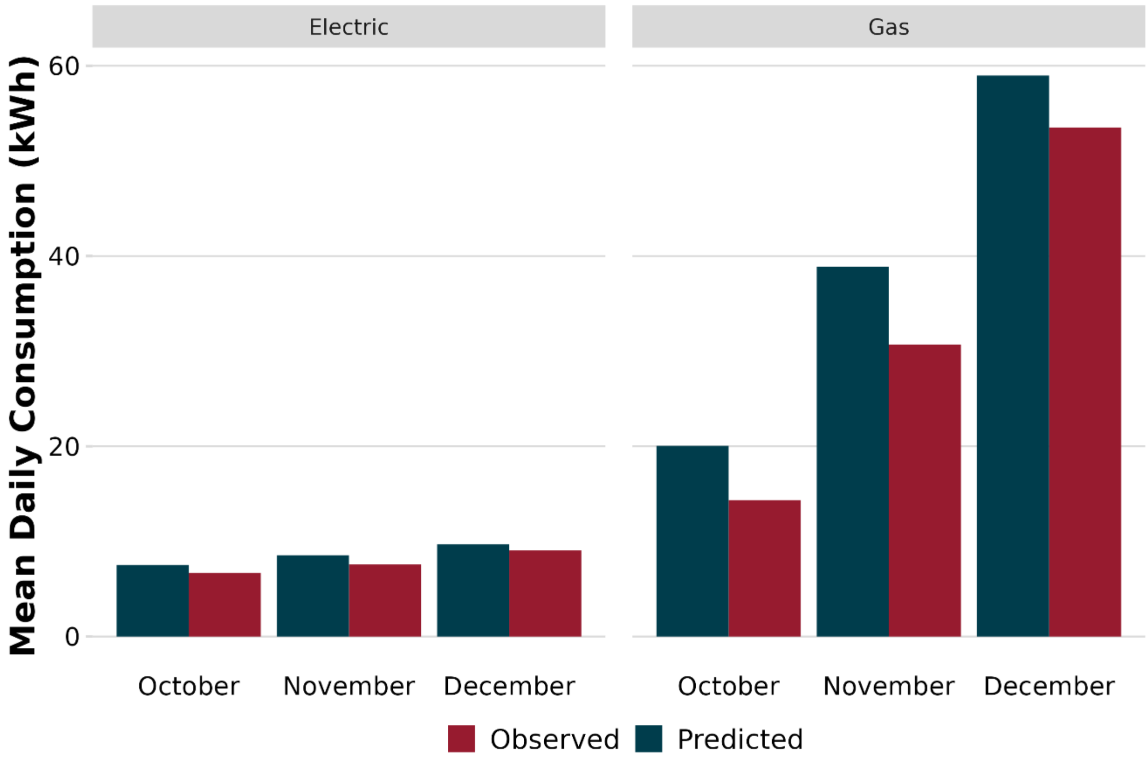


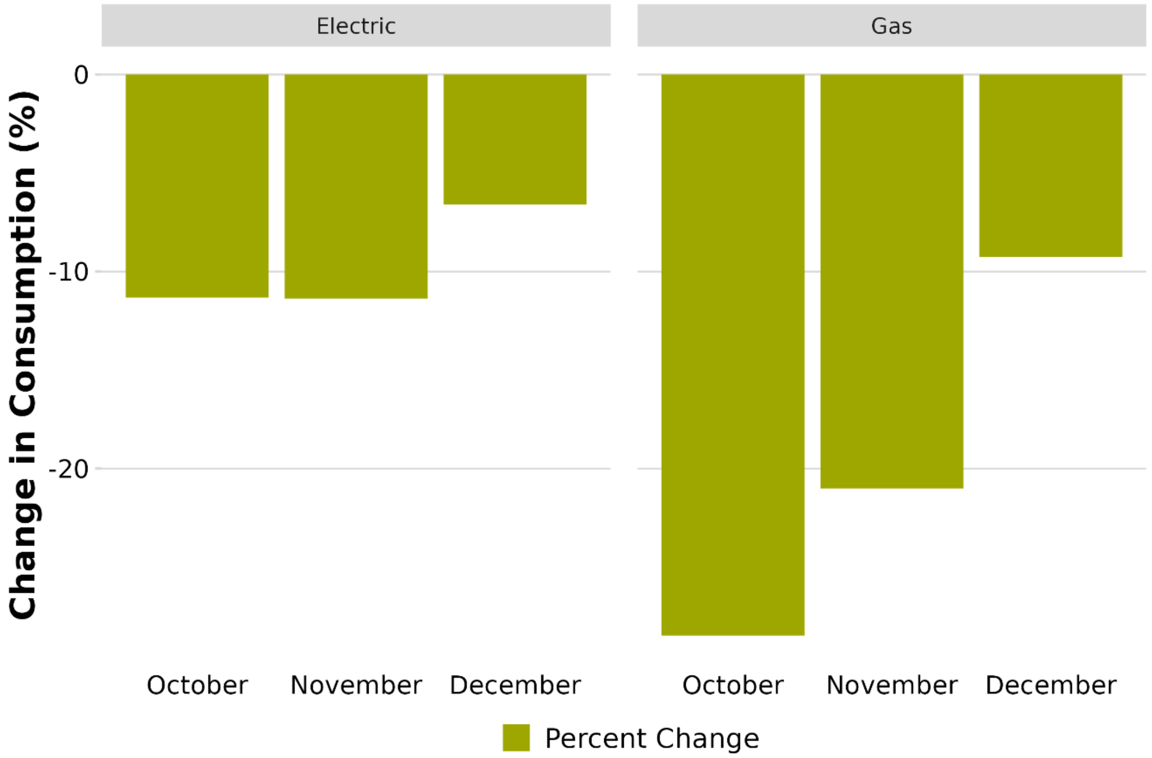
Source: Frontier Economics analysis of SERL data

D.5 Households that are just about getting by

Households that are just about getting by show a very similar story to 'financially struggling' households, but just to a lesser extent. These households tend to have very similar electricity consumption and much lower gas consumption than all households. The change in electricity consumption is larger than average households while the change in gas consumption is much larger than average household changes. While the change in consumption is not as big as for 'financially struggling' households (so observed consumption is higher) consumption still falls to worryingly low levels.

Figure 49 Impact of the cost-of-living crisis on energy consumption for households that are just about getting by

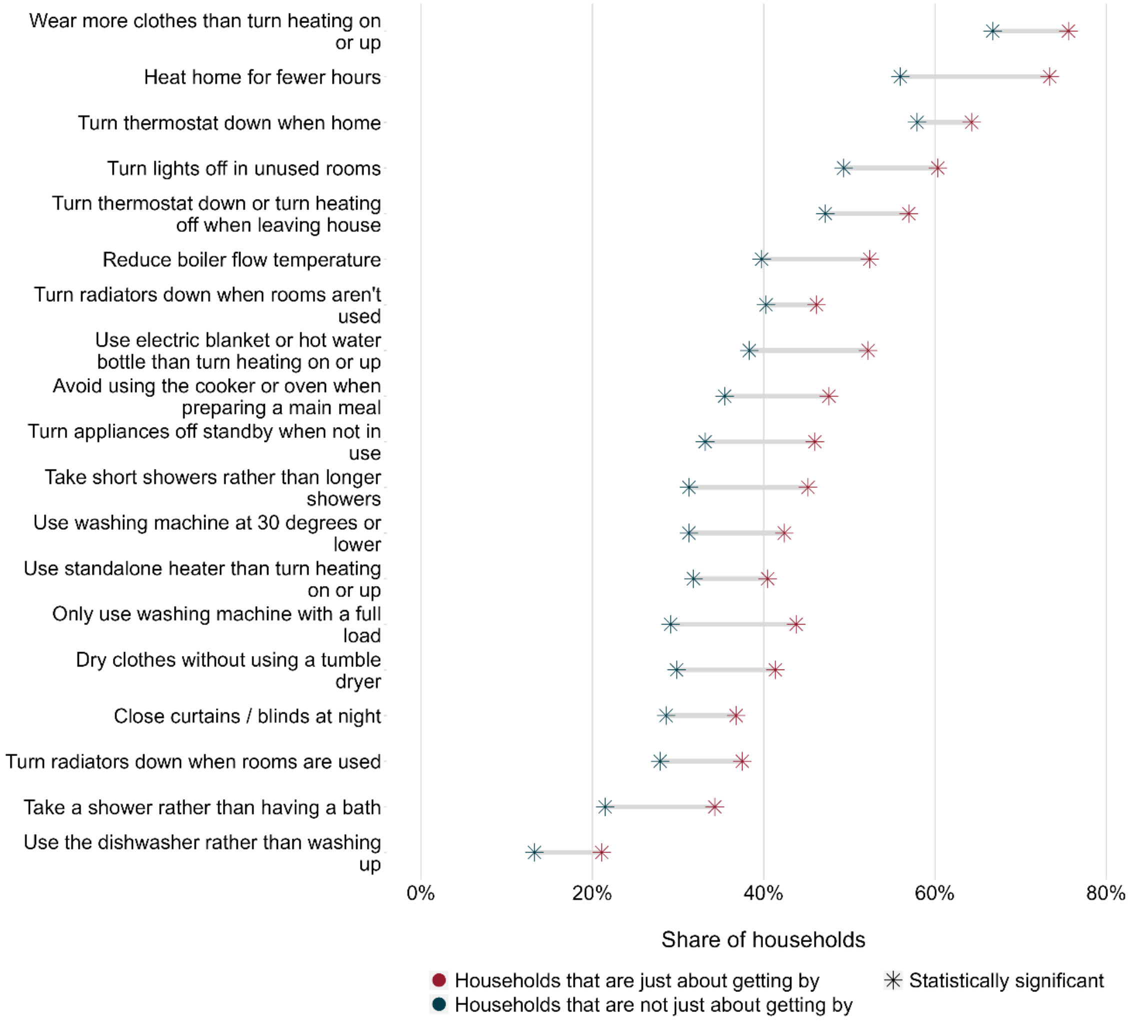




Source: Frontier Economics analysis of SERL data

Again, similar to households that are ‘financially struggling’, the large fall in gas consumption is reflected by these households being more likely to take almost all actions than the average household.

Figure 50 Actions taken by households just about getting by compared to households that aren't just about getting by

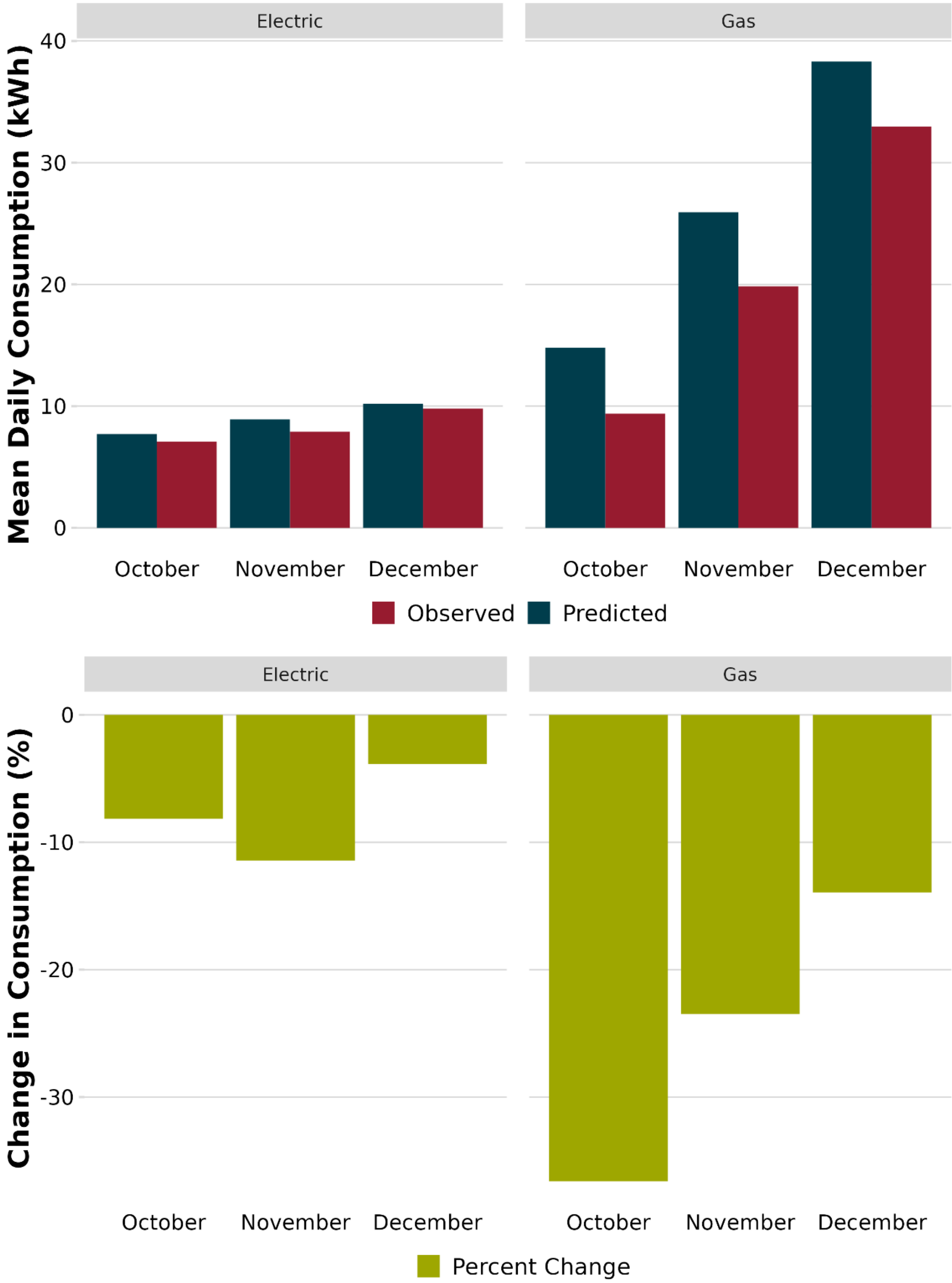


Source: Frontier Economics analysis of SERL data

D.6 Households with pre-payment meters

Households with pre-payment meters have significantly less gas consumption than the average household. The fall in gas consumption is also larger (as a percentage) than other households, albeit lower in numerical terms. The level and change in electricity consumption appears to be more comparable to average households. The change in gas consumption might mean that households are prioritising electricity consumption over heating consumption, which will likely lead to dangerous underheating of homes for these households.

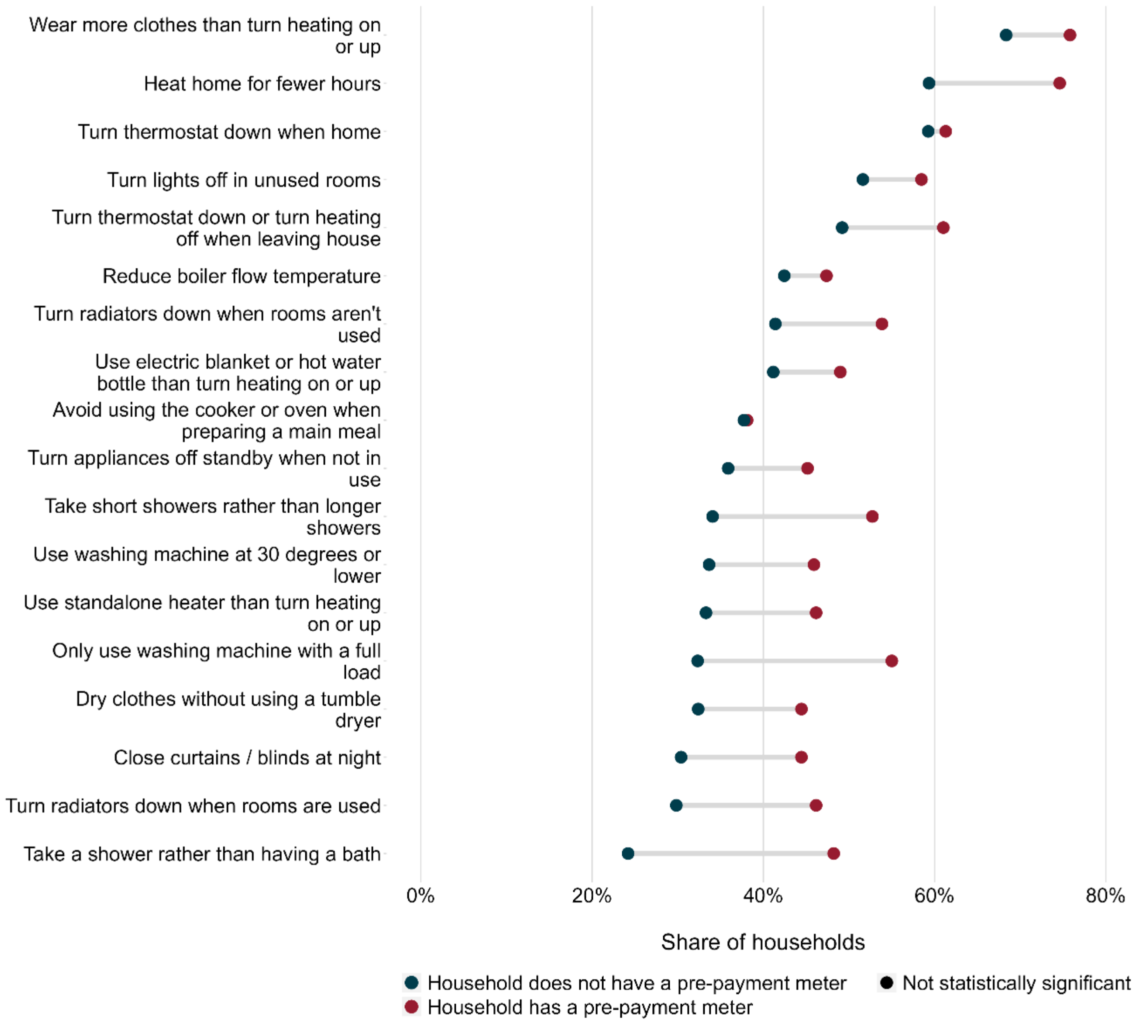
Figure 51 Impact of the cost-of-living crisis on energy consumption for households that have pre-payment meters



Source: Frontier Economics analysis of SERL data

Despite making large changes to gas consumption, these households do not appear to take any actions significantly more than other households. This is likely due to the low sample size of these households.

Figure 52 Actions taken by households with pre-payment meters compared to households that don't have pre-payment meters



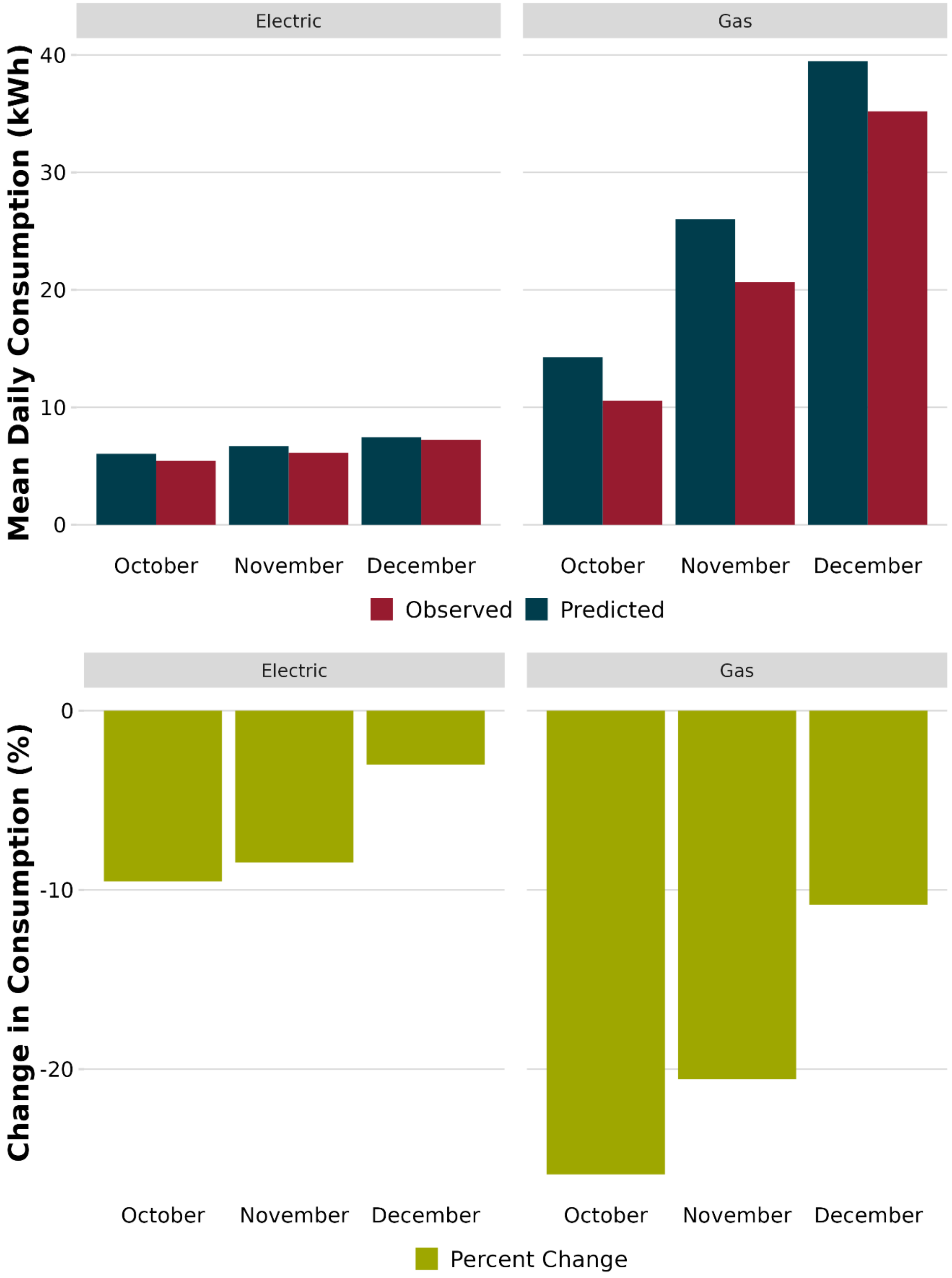
Source: Frontier Economics analysis of SERL data

Note: Due to disclosure policy, we are not showing the action "Use the dishwasher rather than washing up".

D.7 Households in social housing

Households in social housing tend to have much lower electricity and gas consumption than average households. The change in electricity consumption is lower than average households while the change in gas consumption is higher than average households. Much like 'financially struggling', 'just about getting by' and pre-payment meter households, this could lead to dangerous underheating of homes.

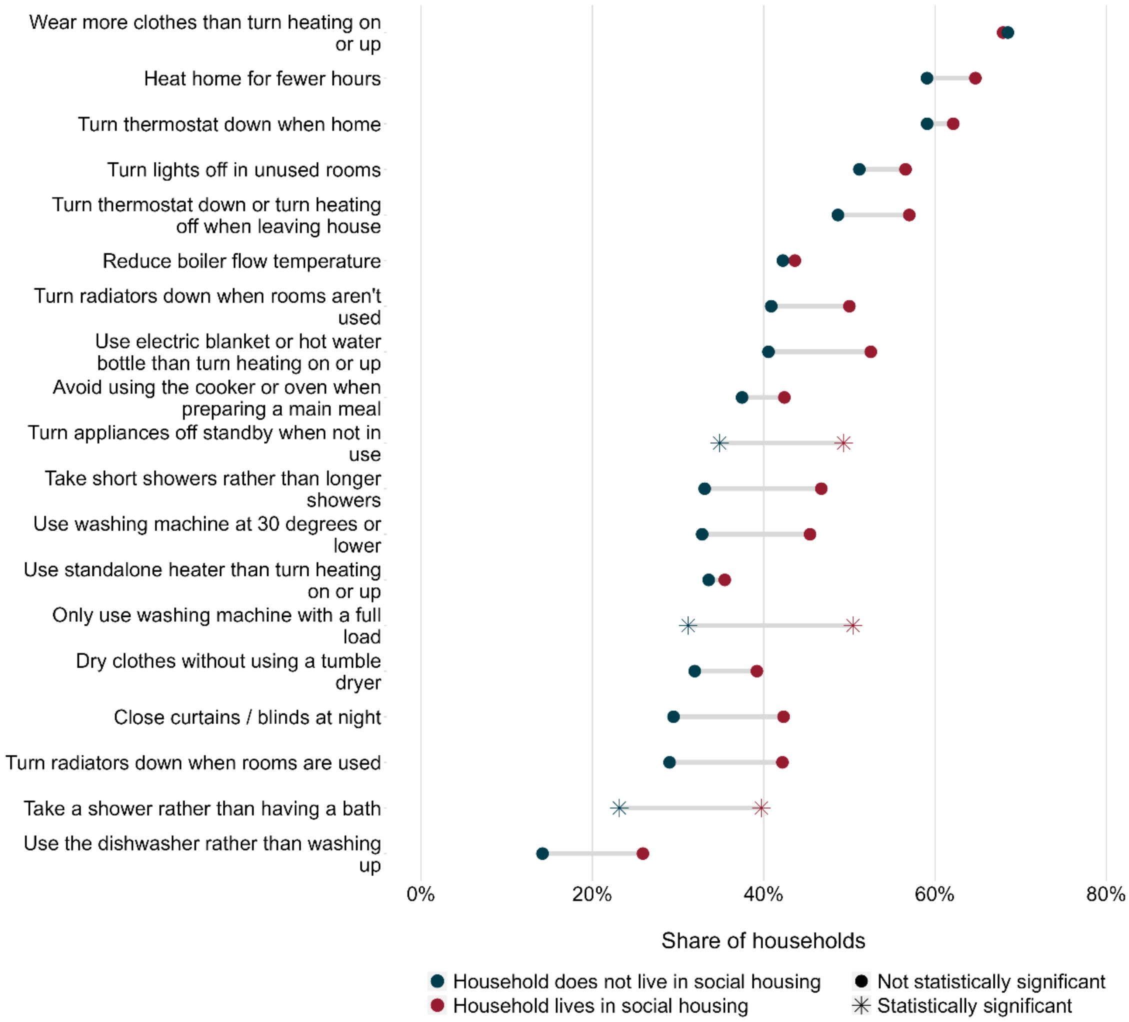
Figure 53 Impact of the cost-of-living crisis on energy consumption for households in social housing



Source: Frontier Economics analysis of SERL data

These households take some actions to a significantly greater extent, but only a small number.

Figure 54 Actions taken by households in social housing by compared to households that aren't in social housing

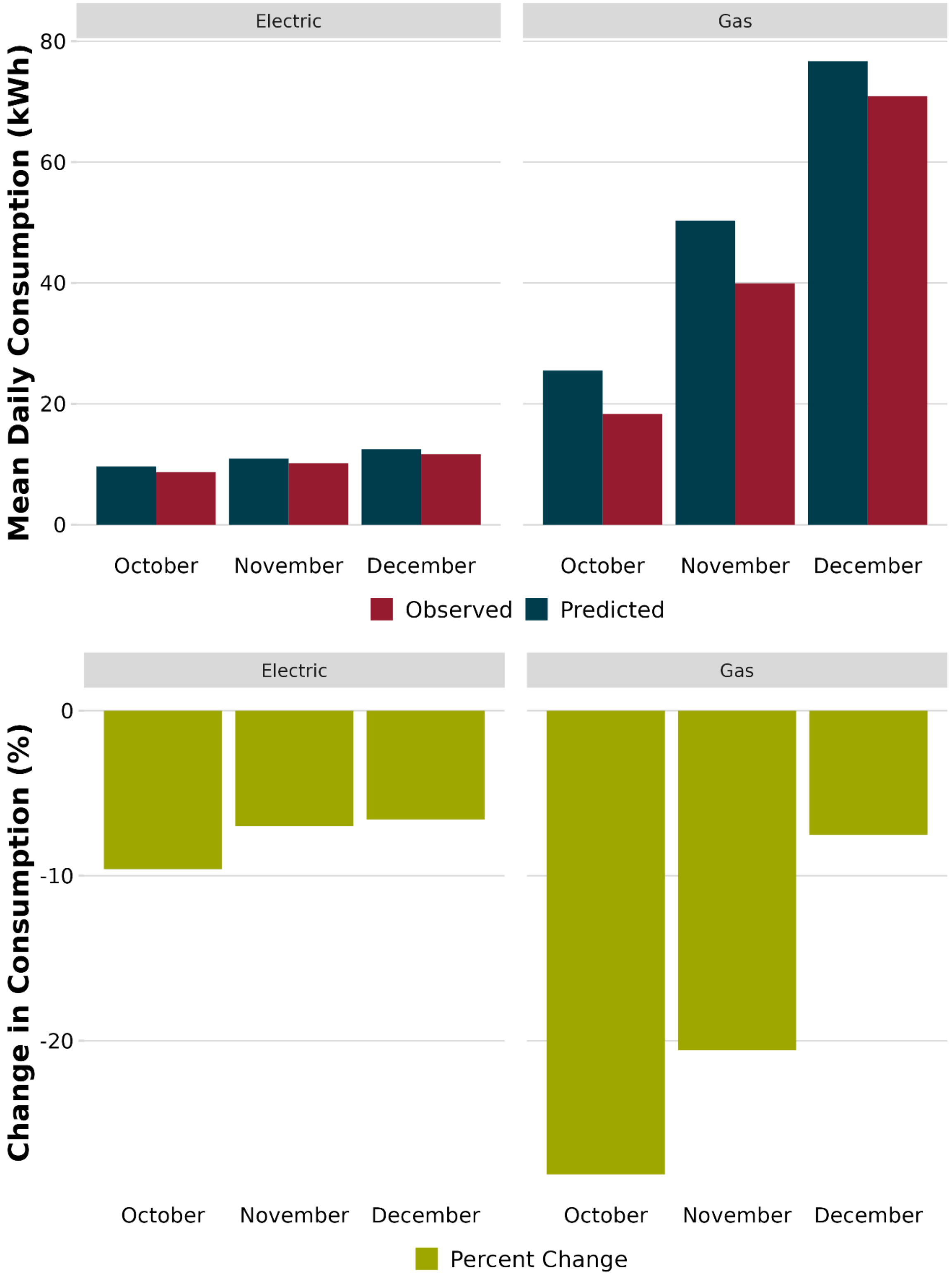


Source: *Frontier Economics analysis of SERL data*

D.8 Households who work from home

Households who work from home use much more electricity and gas than average households. This is unsurprising since these are likely to be households in higher paid jobs and are remaining at home most of the day. The changes in consumption are slightly lower for electricity and slightly higher for gas.

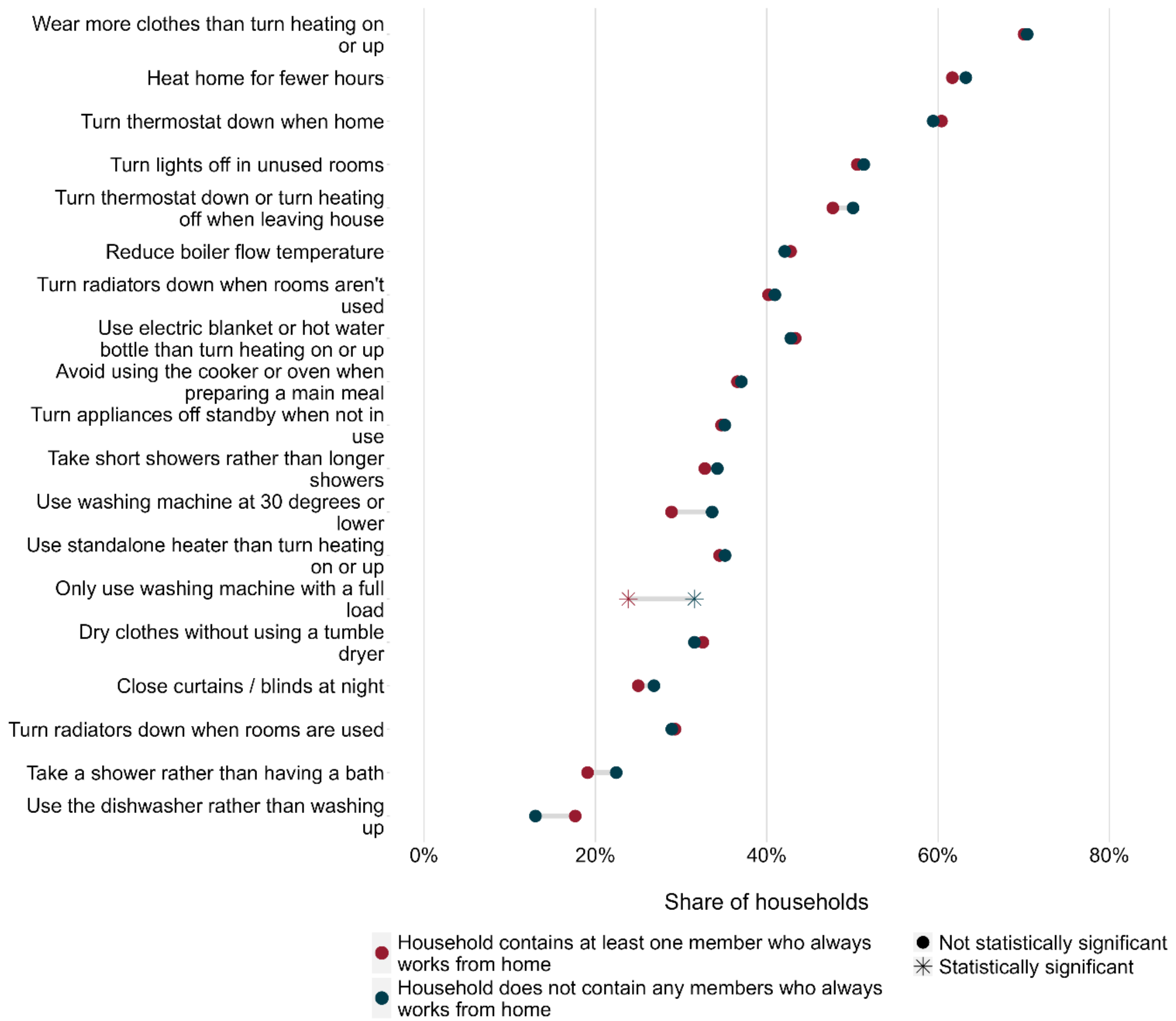
Figure 55 Impact of the cost-of-living crisis on energy consumption for households that work from home



Source: Frontier Economics analysis of SERL data

The extent to which these households take actions is similar to the average household, with only one action being taken significantly less than average.

Figure 56 Actions taken by households where at least one person always WFH compared to households where at least one person always WFH

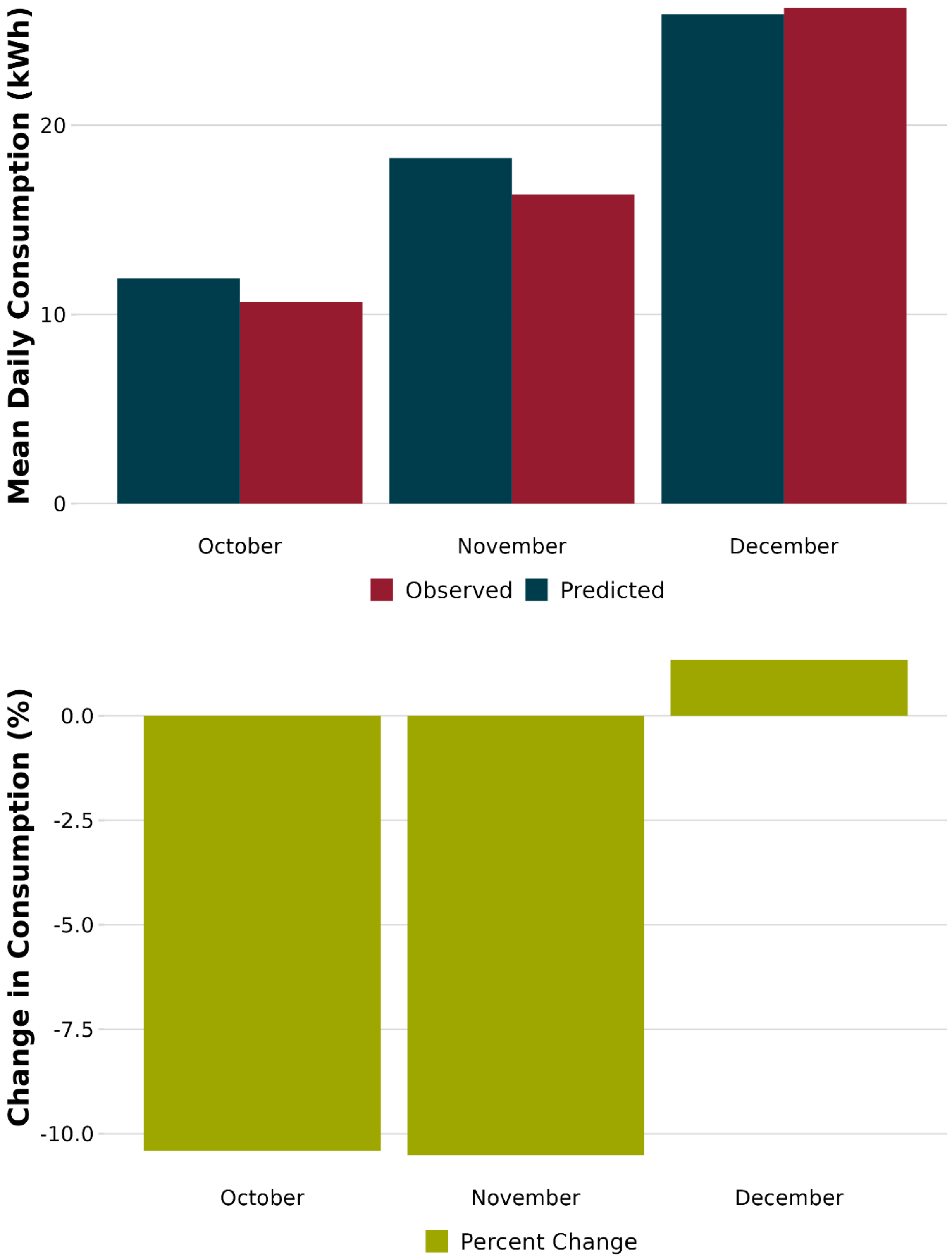


Source: Frontier Economics analysis of SERL data

D.9 Households with electric central heating

Households with electric central heating have higher electricity consumption than average households and lower gas consumption than average households. Electricity consumption reduces about the same as the average household in October and November but reduces much more in December (and actually leads to a small increase in consumption).

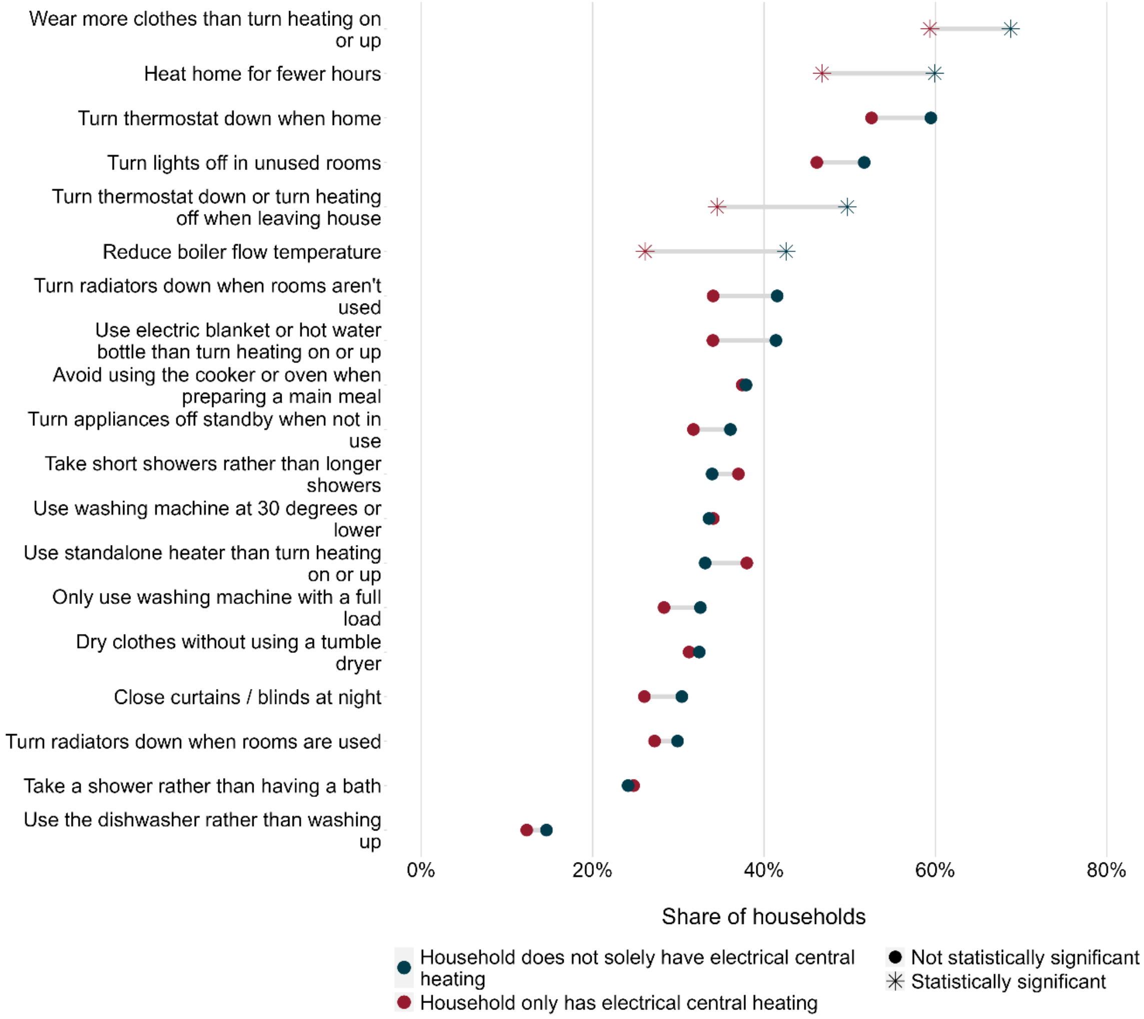
Figure 57 Impact of the cost-of-living crisis on electricity consumption for households with electric central heating



Source: Frontier Economics analysis of SERL data

These households are less likely to take actions leading to changes in heating consumption.

Figure 58 Actions taken by households which only have electrical central heating compared to households that don't only have electrical central heating

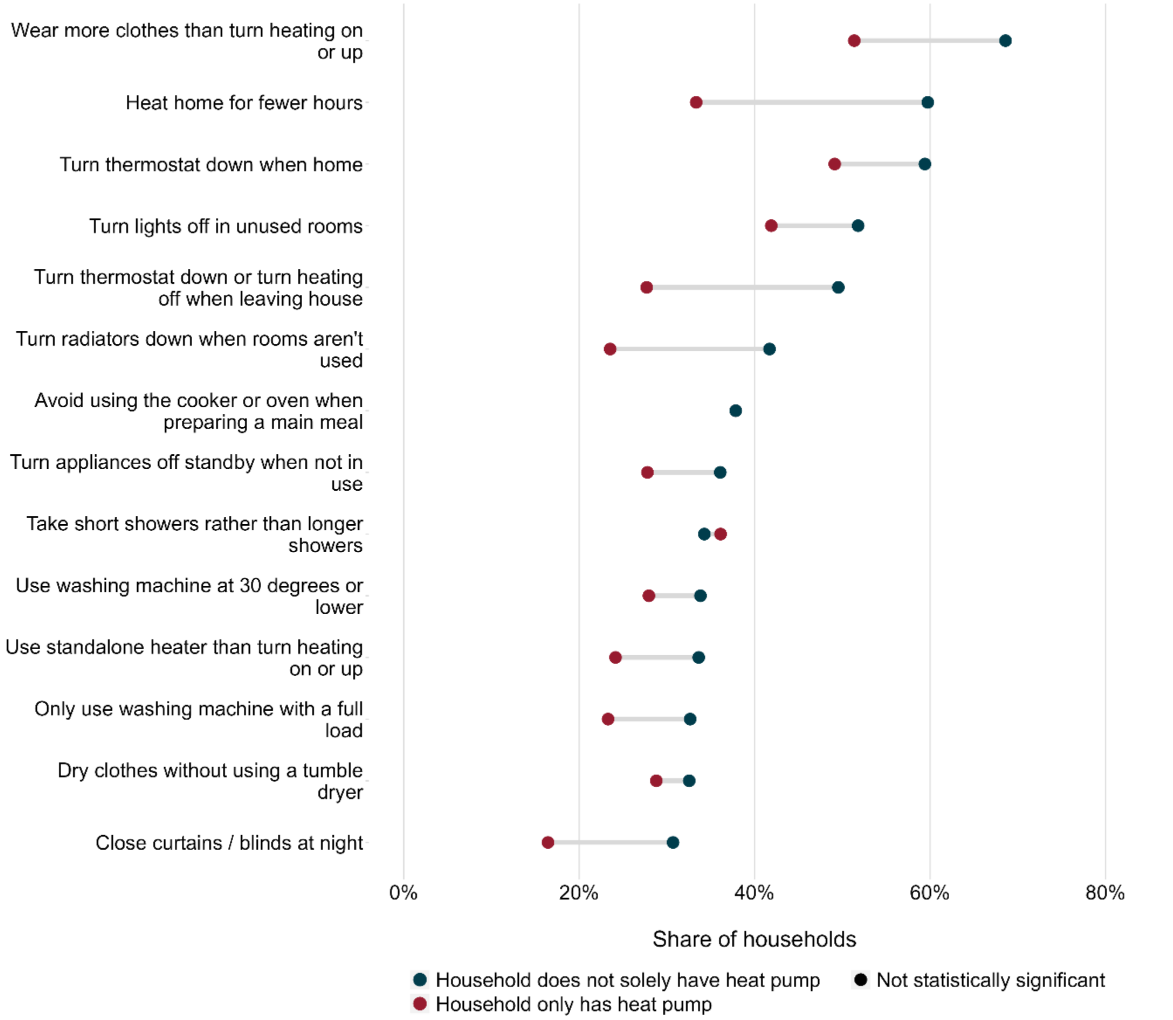


Source: Frontier Economics analysis of SERL data

D.10 Households with heat pumps

Households with heat pumps take far fewer actions than the average household, while there are some actions that heat pump households are not able to do. We have 46 households in this sample.

Figure 59 Actions taken by households that only have heat pumps compared to households that don't only have heat pumps



Source: Frontier Economics analysis of SERL data

Note: Due to disclosure policy, we are not showing the actions 'Reduce boiler flow temperature', 'Take a shower rather than having a bath', 'Turn radiators down when rooms are used', 'Use the dishwasher rather than washing up', and 'Use electric blanket or hot water bottle than turn heating on or up'.

Annex E – the impact of actions on consumption changes

This Annex shows the results from our regression analysis of actions on changes in consumption. In these tables we can interpret significance as whether each action is statistically significant at the 95% level. That means we can be 95% confident that the impact on consumption is different to zero (or a 5% risk that it is not different to zero). When an action is significant, we can reject the null hypothesis that the action is not significant.

Table 10 Impact of energy saving actions on electricity consumption during October to December 2022

Action taken by household	Impact on consumption (kWh)	Significance
Intercept	-58.42	reject the null
Turn lights off in unused rooms	-4.45	do not reject the null
Wear more clothes rather than turn heating on or up	3.79	do not reject the null
Turn thermostat down or turn heating off when leaving house	-1.31	do not reject the null
Use standalone heater rather than turn heating on or up	14.78	reject the null
Use electric blanket or hot water bottle rather than turn heating on or up	-4.13	do not reject the null
Turn radiators down when rooms aren’t used	-10.87	do not reject the null
Turn radiators down when rooms are used	-1.96	do not reject the null
Only use washing machine with a full load	9.62	do not reject the null
Use washing machine at 30 degrees or lower	0.02	do not reject the null

Action taken by household	Impact on consumption (kWh)	Significance
Dry clothes without using a tumble dryer	-10.16	do not reject the null
Turn appliances off standby when not in use	-9.45	do not reject the null
Close curtains/blinds at night	-3.37	do not reject the null
Take a shower rather than having a bath	5.10	do not reject the null
Take short showers rather than longer showers	-10.94	do not reject the null
Use the dishwasher rather than washing up	10.54	do not reject the null
Avoid using the cooker or oven when preparing a main meal	-14.59	reject the null
Reduce boiler flow temperature	-7.60	do not reject the null
Heat home for fewer hours	-10.70	reject the null
Turn thermostat down when home	-7.77	do not reject the null
Turn radiators down when rooms are used – doing this action less	13.58	do not reject the null
Turn radiators down when rooms aren't used – doing this action less	-4.04	do not reject the null
Use electric blanket or hot water bottle than turn heating on or up – doing this action less	-1.79	do not reject the null
Use standalone heater than turn heating on or up – doing this action less	-19.05	reject the null

Action taken by household	Impact on consumption (kWh)	Significance
Turn thermostat down when home – doing this action less	14.28	do not reject the null

Source: Frontier Economics analysis of SERL data
Note: Impact on consumption refers to kWh change in consumption for the whole period October to December 2022.

Table 11 Impact of energy saving actions on electricity consumption during October to December 2022

Action taken by household	Impact on consumption (kWh)	Significance
Intercept	-252.86	reject the null
Turn lights off in unused rooms	65.42	reject the null
Wear more clothes than turn heating on or up	-53.76	do not reject the null
Turn thermostat down or turn heating off when leaving house	-15.93	do not reject the null
Use standalone heater rather than turn heating on or up	-141.97	reject the null
Use electric blanket or hot water bottle rather than turn heating on or up	-154.17	reject the null
Turn radiators down when rooms aren’t used	-31.27	do not reject the null
Turn radiators down when rooms are used	-42.58	do not reject the null
Only use washing machine with a full load	41.08	do not reject the null

Action taken by household	Impact on consumption (kWh)	Significance
Use washing machine at 30 degrees or lower	-19.18	do not reject the null
Dry clothes without using a tumble dryer	56.71	reject the null
Turn appliances off standby when not in use	-35.32	do not reject the null
Close curtains/blinds at night	46.65	do not reject the null
Take a shower rather than having a bath	-51.93	do not reject the null
Take short showers rather than longer showers	11.48	do not reject the null
Use the dishwasher rather than washing up	35.96	do not reject the null
Avoid using the cooker or oven when preparing a main meal	-58.95	reject the null
Reduce boiler flow temperature	-105.92	reject the null
Heat home for fewer hours	-311.65	reject the null
Turn thermostat down when home	-66.18	reject the null
Turn radiators down when rooms are used – doing this action less	69.12	do not reject the null
Turn radiators down when rooms aren't used – doing this action less	-14.34	do not reject the null
Use electric blanket or hot water bottle than turn heating on or up – doing this action less	-67.27	do not reject the null

Action taken by household	Impact on consumption (kWh)	Significance
Use standalone heater than turn heating on or up – doing this action less	-54.09	do not reject the null
Turn thermostat down when home – doing this action less	102.10	reject the null

Source: Frontier Economics analysis of SERL data

Note: Impact on consumption refers to kWh change in consumption for the whole period October to December 2022.