Energy Policy 214 (2026) 115260

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Policy design challenges for energy affordability following price hikes in the UK

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ARTICLE INFO

Keywords:
Affordability
Asset
Income
Distribution
Electricity
Poverty

ABSTRACT

Energy affordability is a persistent challenge for households which has recently become more pronounced. Using the UK Understanding Society household survey, we assess variables related to energy affordability with waves on either side of energy-price hikes which followed the onset of heightened geopolitical conflict in 2022. We find that the link between income and energy expenditure is strongest for the highest part of the income distribution. Key socioeconomic factors linked to problems paying energy and other bills are renting and an asset index, based on our linear probability and multinomial logit regressions. For households in the bottom asset quintile, renters are more likely to experience bill-paying problems by around 17 percentage points. Using Locally Weighted Scatterplot Smoothing, we find that problems paying bills are most pronounced for the bottom income quintile, while energy expenditure rises most from the fourth to the highest quintile. One policy implication is the need for greater consideration of persistent bill-paying problems such as with educational programs. Targeting support more precisely is also justified based on analysis of economic distributions such as further supporting the bottom asset or income quintiles and increasing support for renters particularly when they also have low asset levels. Composite policies supporting investments in energy sources beyond only solar panels would also have value.

1. Introduction

1.1. Motivation

Affordability of energy is a major issue in many developed countries. The focus on energy affordability has been pronounced in recent years, with geopolitical conflict leading to price hikes which were particularly acute for electricity and gas from the middle of 2022 onwards. Existing policy challenges related to household energy expenditure or affordability pressure have therefore intensified over the last few years. This creates urgency and potential for new policy designs to provide widespread benefits.

Following Russia's invasion of Ukraine in February 2022, there was a surge in retail energy prices in the United Kingdom (UK) from the middle of 2022 onwards (Office for Budget Responsibility, 2023). Prices rose by 129% for gas and 66% for electricity when comparing October 2022 to October 2021, which were the largest annual increases in the data series starting in 1970 (Bolton and Stewart, 2025). These energy price increases made the largest contribution of any sector to overall consumer price inflation in late 2022 (Office for National Statistics, 2022b).

In response to price hikes, there was a flurry of government policies such as numerous one-off energy bill discounts and changing energy price caps (Bolton and Stewart, 2025). Table 1 summarizes key policies which include a mix of universal and restricted-eligibility approaches.[1] While these were major government outlays and helped to lower retail energy bills below what they would have been without support, households still experienced substantially higher energy bills (Bolton

This article is part of a special issue entitled: Energy Geopolitical Fragmentation published in Energy Policy.

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[1] Some of these policies have been universally available, rather than restricting eligibility based on the economic characteristics of the household. In contrast, other policies have used means testing, where the means or ability of the household is used to determine eligibility for policy support by excluding households having the ability to more comfortably pay for energy without government support.

https://doi.org/10.1016/j.enpol.2026.115260
Received 6 November 2025; Received in revised form 18 February 2026; Accepted 12 March 2026
Available online 16 March 2026

Table 1
Key energy-specific policies in the UK for mitigating effects of energy cost spikes for private households.

Policy name	Summary	Covered households
Energy Price Guarantee	Introduced in October 2022 to cap gas and electricity bills to £2500 per year for a typical household.	All (but households still pay more where consumption of energy is higher than typical).
Energy Bills Support Scheme	A £400 discount on electricity bills in the winter of 2022-23.	All
Pensioner Cost of Living Payment	A payment of up to £300 in the winter of 2022-23, paid as an increase to the Winter Fuel Payment.	Pensioners only (restricted to older and low-income recipients)
Warm Home Discount Scheme	Annual £150 discount on electricity bills from 2022 to 23 (extending the previous £140 discount).	Pensioners and low-income
Alternative Fuel Payment	A one-off £200 bill discount (or direct bank payment), generally in February 2023.	Households using alternatives to mains gas as their primary heating source (e.g. oil).

Sources: Bolton (2025); Bolton and Stewart (2025); UK House of Commons (2025)

and Stewart, 2025). The UK House of Commons (2025) recognizes that policy reform is needed to better target support based on household need. This implies that design challenges for future policies include identifying which household groups have the greatest need for energy support.

There is also a long history of focus on energy affordability in the UK. Boardman (1991) provided a seminal contribution to fuel poverty research in developed countries, while referring to 10% of income being spent on energy as a threshold to identify households experiencing energy-related affordability pressure. Focus on poverty is also evident in the 2012 Hills report (Hills, 2012), which considered a low-income/high-cost definition of fuel poverty. Focus on energy affordability continues with the consideration of a range of measures related to energy affordability, such as a Low-Income Low Energy Efficiency (LILEE) indicator, although questions have also been raised about this indicator (Semple et al., 2024). It is likely that no single metric is ideal.

In this paper, we focus on specific distributional variation in energy outcomes of energy expenditure and problems paying energy and other bills. We seek to link these outcomes and to integrate consideration of upfront energy investments affecting both energy expenditure and affordability. Trade-offs between spending on energy and other sectors are also important, motivating consideration of bill-paying problems across sectors (Best, 2022a).

1.2. *Household energy consumption and expenditure*

Factors influencing electricity and other energy consumption and expenditure in domestic contexts have received considerable attention. A review by Jones et al. (2015) split factors into three main categories of socioeconomic, dwelling, and energy appliances or technologies. Their review mostly covered developed countries, identifying the most studied factors as household income, the number of occupants, and household size. They found that positive relationships between these variables and electricity consumption were often evident.

A range of insights has been gained from prior studies for the UK and other developed countries. Household energy consumption in the UK is highly influenced by many factors including income (Druckman and Jackson, 2008), dwelling characteristics (Wyatt, 2013; Huebner et al., 2015; Li and Lomas, 2025; Dejkam and Madlener, 2025), and behavioural variables (Satre-Meloy and Hampton, 2024). Studies for the United States (US) also emphasize the importance of housing tenure (Best et al., 2021; Davis, 2023). Assets were a crucial determinant of energy expenditure in an Australian study (Best and Burke, 2022), although variables related to wealth are rarely assessed. Wealth has been excluded from prior studies if data are difficult to obtain, while some studies focus on homeowners rather than renters.

1.3. *Fuel poverty and affordability*

The term ‘fuel poverty’ has been widely used in the UK since the 1980s (Li et al., 2014). An initial issue is understanding and clearly defining fuel poverty, as this influences how policy support is targeted (Moore, 2012). The terms ‘fuel poverty’ and ‘energy poverty’ both refer to accessibility of affordable energy, with ‘fuel poverty’ focusing more on affordability in developed countries while ‘energy poverty’ tends to be used more broadly to also incorporate energy accessibility and developing countries.

Fuel poverty is an important issue in the UK, with wide ranging influences, such as on financial distress and health (Burlinson et al., 2021; Davillas et al., 2022). Health links can be both physical and mental (Awaworyi Churchill et al., 2020; Khavandi et al., 2024). The challenges have been persistent in the UK, with previous improvement targets not being met (Liddell et al., 2012). Given that fuel poverty has broad overlaps with other aspects such as housing costs (Burlinson et al., 2018), trade-offs are important to consider between energy and other expenditure (Burlinson et al., 2022; Champagne et al., 2024). Problems with paying various types of bills including for energy, water, phones, and other uses, are therefore linked.

The affordability aspect of fuel poverty discussed in this section relates to energy expenditure covered in section 1.2, as higher energy expenditure likely raises the difficulty for paying energy bills. There are also potentially similar variables influencing energy expenditure and the affordability aspect of fuel poverty, as having more income and assets is likely linked to higher energy expenditure but less difficulty for affording energy bills.

1.4. *Contributions*

Our original contributions relate to the key research question: how do socioeconomic characteristics relate to household energy affordability? While this may initially appear to be a mundane question, several factors make this a crucial question. Energy challenges for households are widespread and persistent, and worsening following recent price hikes. Past research and policies have not been sufficient to address the challenges faced by households. Policymakers are aware of the need for an improved understanding to inform better targeting of policies in the future based on household need (UK House of Commons, 2025).

The novelty of our analysis includes (1) distributional focus comparing energy outcomes before and after price hikes (through LOWESS analysis), (2) focus on assets beyond just income (with an asset index in regressions), (3) consideration of both persistence and changes (with lagged dependent variables, explanatory variables for changes, and a multinomial logit model), and (4) assessment of links between energy spending and problems paying bills (using similar explanatory variables and with energy expenditure as an explanatory variable when problems paying bills is a dependent variable). These four contributions in a household energy context allow for quantification of impacts, such as the link between income and problems paying energy bills. This type of analysis can help policymakers recognizing that subsidies should be targeted more precisely based on household need (UK House of Commons, 2025).

Our analysis of assets can be useful given its strong intuitive and empirical relevance for affordability problems in other countries (Best, 2022a). While wealth variables have been used in several studies including for the US (Best, 2022b) and countries in South Asia (Abbas et al., 2020), wealth is mentioned far less than income in a systematic literature review of energy poverty determinants (del Río et al., 2025) and is less frequently used in policies. Previous schemes using assets in means testing indicate feasibility (Graff and Pirog, 2019).

The contributions of the paper are amplified following recent geopolitical events, as higher energy prices for households is a widespread issue across countries. Higher housing costs in many countries also increase the importance of our assessment of adverse outcomes for renters, given the strong relevance of housing for fuel poverty (Burlinson et al., 2018). Our analysis also incorporates possible energy investments like solar panels, which have been growing in popularity, and possible fuel-type switching evident in expenditure changes.

2. Data and method

2.1. Data

We use the UK Understanding Society household survey from the University of Essex. From this longitudinal survey, we use the three waves from 2020 to 21, 2021-22, and 2022-23. Our LOWESS analysis uses all three waves, while our regressions include the two waves on either side of the energy price hikes from 2022. We combine the advantages of using the detail in household-level data with the variation across more than one cross-section for the same households. There is substantial cross-sectional variation in household-level outcomes, which is useful to identify differences across household characteristics which can directly inform policy designs. Our focus on two adjacent waves is also useful to reduce issues related to household composition changes, given that the longitudinally tracked household reference person can be a member of a different household in different waves.

The data provide a nationally representative sample of UK households. Our regressions use probability weights to give more weight to households who represent a larger share of the population, based on the sampling approach. The data also include many variables which we can use as controls, helping to isolate influences of key variables. Our regression analysis and the descriptive statistics reported in Table 2 cover households which have data for each of the included variables.

Many of the explanatory variables, and the bill-paying problem dependent variable, are categorical (such as binary). We also created an asset index based on variables in the survey: home value for owners, the value of second properties, the value of vehicles owned, and the values of four categories of financial investments (savings, trusts, shares, and other investments including bonds/gilts). We used the first principal component from principal components analysis and then created an asset quintile variable to align with an income quintile variable. For income and assets, having five categories is useful to assess possible non-linearity of economic influences on energy outcomes. An income change variable is a binary variable equal to one for households in the top quintile based on income change for the last year, and zero for all others. We calculated the change in income and then produced a quintile variable, but we only use a binary variable for the top income quintile to focus on large income increases and avoid an excessive number of covariates.

Table 2 shows proportions for categorical variables or mean values for numerical variables. For example, there are 5% and 6% of households experiencing problems paying bills in 2021-22 and 2022-23 respectively, while the mean energy expenditures (all types) are £1352 and £1756 per year for the corresponding survey waves. The proportions in quantiles can vary when households are dropped due to dropping observations after we calculate quantiles (when other variables are unavailable for our regressions). We consistently use the same explanatory variables with several different dependent variables and sample sizes.

2.2. Method

We used the UK Understanding Society household survey to assess key research questions of socioeconomic and other determinants related to household energy affordability. Independent variables are based on survey questions and include income and asset quintiles as key economic components, with many other included variables relating to housing, location, and demographic aspects. The large set of independent variables is important for complex contexts for energy affordability (Dejkam and Madlener, 2025; Al Kez et al., 2024; Baker et al., 2018).

Table 2
Proportions or means; full sample and income quintile (IQ) sub-samples.

	Full	IQ1	IQ2	IQ3	IQ4	IQ5
Electricity & gas expenditure 2021-22#	1261	1005	1115	1254	1361	1569
Electricity & gas expenditure 2022-23#	1642	1263	1443	1639	1757	2102
Energy expenditure 2021-22#	1352	1067	1192	1347	1462	1691
Energy expenditure 2022-23#	1756	1345	1537	1754	1876	2263
Problem paying bills 2021-22	0.05	0.09	0.05	0.05	0.04	0.02
Problem paying bills 2022-23	0.06	0.10	0.07	0.06	0.05	0.03
Income change; quintile 5	0.18	0.18	0.13	0.18	0.21	0.22
Renter	0.23	0.36	0.29	0.21	0.17	0.08
Mortgage	0.34	0.14	0.18	0.29	0.45	0.63
Asset index#	3.24	2.44	2.85	3.26	3.58	4.06
Occupants; OECD equivalized#	1.61	1.21	1.38	1.62	1.81	2.04
Occupants change (equivalized)#	0.00	0.01	0.00	0.00	−0.01	−0.02
Number of bedrooms#	2.99	2.45	2.70	3.02	3.19	3.56
Change in number of bedrooms#	0.00	0.00	0.00	0.00	0.00	0.00
Solar panels	0.06	0.04	0.05	0.06	0.06	0.08
No central heating	0.15	0.15	0.13	0.15	0.15	0.16
Solar water heating	0.02	0.01	0.02	0.02	0.02	0.03
Fuel oil expenditure#	69.52	49.58	55.20	68.08	71.34	98.33
Change in fuel oil expenditure#	19.42	17.51	13.90	18.50	15.59	31.79
Expenditure; other energy types#	22.25	11.50	21.63	24.51	29.46	23.64
Gap between interviews-months#	11.84	11.89	11.83	11.81	11.83	11.83

Notes: This sample covers the 9′444 observations for which there are no missing variables for our first regression. There is a larger sample size for subsequent analysis, as more observations have a response for problems paying bills, compared to energy expenditure. Values are proportions unless identified as a mean (#). There are also location controls for 12 regions based on the "Government Office Region" and a binary variable distinguishing between rural and urban areas. There is also a survey month control (24 possible months in 2021-22 plus a small 25th category for delayed interviews in early 2023). "Energy expenditure" includes these types: electricity, gas, oil, and "other".

2.2.1. Regressions

Equation (1) shows the dependent variable (*D*) for each household (*h*) in the 2022-23 wave. This is explained by socioeconomic (*S*), housing (*H*), and location (*L*) variables. We conduct separate regressions for the log of electricity and gas expenditure, the log of energy expenditure which also includes fuel oil and other sources, and bill-paying problems related to electricity or gas or other household bills. We use the same structure to assess both bill-payment difficulties and energy expenditure, so the dependent variable (*D*) is for each of these contexts separately in the respective regressions in Section 3. As the bill-paying problems variable is binary, we start with a linear probability model in that case.

$$D_{h,22-23} = c + \gamma S_{h,21-22} + \theta H_{h,21-22} + \zeta L_{h,21-22} + \delta D_{h,21-22} + \varepsilon_h \quad (1)$$

A key aspect in equation (1) is the lagged dependent variable (*D*) in a cross-sectional context. This is useful to control for otherwise unobserved heterogeneity as the lagged energy outcome will be correlated with other relevant explanatory variables which are difficult to control for, such as additional detailed housing characteristics. Including the lagged dependent variable leads to higher *R*-squared values and indicates the extent of persistence.

With the lagged dependent variable as an explanatory variable, the interpretation of other independent variables changes from influences on levels to influences on changes. This is evident in equation (2) explaining the level and equation (3) explaining the change, while being identical other than the offsetting impact of subtracting a common term ($D_{h,21-22}$) from both sides of equation (3). Variables with robust influences on energy outcomes across time would be evident in results explaining both levels (without the lagged dependent variable) and changes in the dependent variable (from including the lagged dependent variable).

$$D_{h,22-23} = c + \gamma S_{h,21-22} + \theta H_{h,21-22} + \zeta L_{h,21-22} + \delta D_{h,21-22} + \varepsilon_h \quad (2)$$

$$D_{h,22-23} - D_{h,21-22} = c + \gamma S_{h,21-22} + \theta H_{h,21-22} + \zeta L_{h,21-22} + (\delta - 1) D_{h,21-22} + \varepsilon_h \quad (3)$$

To assess the potential for changes in bill-paying problems from before and after the 2022 energy price hikes, we use a multinomial logit model. This has four levels (*k*) based on binary variables for bill-paying problems for the 2021-22 and 2022-23 waves. The four unordered levels are experiencing no problems in either period, changing from no problems in 2021-22 to then experiencing a problem in 2022-23, changing in the opposite direction, and experiencing problems in both periods. This is useful to simultaneously assess either persistence or changes. Given that the four-category dependent variable effectively includes a lag of the energy outcome, we do not include the *D* variable from previous equations as an explanatory variable. We can compare relative marginal effects to see if socioeconomic and housing variables have different influences, or are more influential, in explaining persistence or changes in bill-paying problems. The multinomial model is given in equation (4):

$$ln\left(\frac{prob(D = outcome\ k)}{prob(D = outcome\ 4)}\right) = c + \gamma S_{h,21-22} + \theta H_{h,21-22} + \zeta L_{h,21-22}, \quad k = 1, 2, 3. \quad (4)$$

2.2.2. LOWESS

The LOWESS method conducts local bivariate regressions around each value along the *x*-axis, which in our case is for household income percentiles. This means that separate regressions are run for each point along the *x*-distribution. These local regressions draw on variation around the *x*-value within a specified bandwidth, or local neighbourhood. The data within the neighbourhood are weighted to give higher weights to observations which are closer to the assessed point. We use the default bandwidth in Stata of 80% of observations, which can incorporate 40% of *x*-values on either side of the specified *x*-value. However, near the end points of the *x*-distribution, the smoothing process does not have access to a full and symmetric local neighbourhood and so smaller uncentred subsets are used. In effect, the LOWESS method is like a rolling average of the outcome variables at each point along the *x*-axis distribution. For LOWESS analysis of the binary outcome of problems paying bills, we use a logit model before calculating the odds ratio and probability of experiencing problems.

LOWESS has several advantages which motivate its application to distributional contexts. LOWESS provides transparent visualization of full distributions, accounting for possible non-linearity. The weighting approach helps to reduce the influence of outliers, while also boosting precision through the higher weights for local data. This allows for assessments of the level, shape and turning points for the outcome variable.

LOWESS can produce probability plots like kernel density plots, but LOWESS involves a second variable for the x-axis. LOWESS can give similar visual information to a histogram, although LOWESS gives a smoothed and continuous curve contrasting to the discrete categories for a histogram. A shift up for more recent data will be evident with either approach when there is an increase in the outcome variable, for a given distributional shape.

Previous use of LOWESS includes analysis by Olabisi et al. (2019) who assessed budget shares for three energy types across the distribution for the log of total household expenditure. Yuan and Choudhary (2023) assessed changes in emission variables across distributions for their initial levels.

We assess the two outcomes of energy expenditure and bill-paying problems across household income distributions. We can then compare these distributions over time, including before and after energy price hikes. LOWESS analysis gives a clear view on the slope and shape across distributions, along with comparisons across the different distributions.

3. Results

3.1. Regressions

Table 3 has results explaining the log of energy expenditure. In column (1), the energy expenditure includes each of electricity, gas, fuel oil, and other energy sources. This column has a lagged dependent variable as an explanatory variable, and so is equivalent to assessing influences on the change (Δ) in the dependent variable. There are very similar results in column (2) when the dependent variable is the log of only electricity and gas, other than expected differences for lagged fuel oil and other energy expenditure. In addition, there are similar narratives when dropping an explanatory variable for the lagged log energy expenditure in column (3), meaning that this column explains the level of the (logged) dependent variable. Multicollinearity does not appear to be an issue as the variance inflation factors are below 3.7 with an average of 1.7, as evident in Appendix Table A.1.

Higher income is associated with higher electricity and gas expenditure in Table 3. There are interesting distributional patterns evident. The bottom income quintile appears to be substantially different to all other quintiles. Also, the middle three quintiles appear to be quite similar to each other. In contrast, the highest income quintile has a larger coefficient magnitude. For example, the coefficient of 0.191 for the highest income quintile in column (1) is statistically different to the coefficient of 0.106 for the second-highest income quintile. The same outcome is evident for column (2).

A larger income change is also associated with higher energy expenditure in Table 3. This is based on a binary variable equal to one for households in the top quintile based on income change for the last year. The coefficient for explaining log energy expenditure is approximately 0.06 in each case. For the log-linear model, this implies that

Table 3
Results explaining log energy expenditure.

	(1; Δ)	(2: Δ)	(3; level)
Ref: income quintile 1			
Income quintile 2	0.094***	0.096***	0.111***
	(0.027)	(0.027)	(0.028)
Income quintile 3	0.104***	0.107***	0.138***
	(0.026)	(0.027)	(0.027)
Income quintile 4	0.106***	0.106***	0.147***
	(0.028)	(0.028)	(0.029)
Income quintile 5	0.191***	0.200***	0.249***
	(0.031)	(0.031)	(0.032)
Quintile 5: change in income	0.065***	0.060***	0.057**
	(0.021)	(0.022)	(0.023)
Renter	−0.087***	−0.069**	−0.114***
	(0.029)	(0.029)	(0.028)
Mortgage	−0.070***	−0.053***	−0.107***
	(0.020)	(0.020)	(0.020)
Ref: asset quintile 1			
Asset quintile 2	0.045	0.035	0.061*
	(0.034)	(0.034)	(0.032)
Asset quintile 3	0.055	0.050	0.065**
	(0.034)	(0.034)	(0.031)
Asset quintile 4	0.045	0.035	0.043
	(0.036)	(0.036)	(0.033)
Asset quintile 5	0.094**	0.090**	0.123***
	(0.037)	(0.038)	(0.034)
Occupants; equivalized	0.126***	0.129***	0.202***
	(0.022)	(0.022)	(0.022)
Change; occupants; equivalized	0.236***	0.223***	0.269***
	(0.075)	(0.076)	(0.070)
Bedrooms	0.091***	0.090***	0.147***
	(0.011)	(0.011)	(0.011)
Change; bedrooms	0.139***	0.138***	0.149***
	(0.035)	(0.036)	(0.033)
Solar panels	−0.075**	−0.076**	−0.115***
	(0.036)	(0.037)	(0.041)
No central heating	−0.036	−0.042	−0.071**
	(0.029)	(0.029)	(0.029)
Oil expenditure	0.287***	−0.204***	−0.264***
	(0.019)	(0.025)	(0.028)
Change; oil expenditure	0.333***	−0.107***	−0.155***
	(0.025)	(0.038)	(0.038)
Other energy expenditure	0.313***	−0.099	−0.062
	(0.057)	(0.062)	(0.076)
Log electricity and gas spend	0.321***	0.344***	
	(0.020)	(0.020)	
Problem paying bill	0.087*	0.090*	0.065
	(0.051)	(0.051)	(0.056)
Number of observations	9′444	9′444	10′669
Adjusted R^2	0.320	0.302	0.205

Notes: Locational controls, insignificant solar water heating, the survey month (24 possible months in 2021-22 plus a small 25th category for delayed interviews in early 2023), the gap between household interviews in months, a small category where tenure is not disclosed, and constants are not shown. Statistical significance is indicated by: *** (1%), ** (5%), and * (10%).

being in the top quintile for income change is associated with approximately 6% higher energy expenditure for the final column (or the change in energy expenditure for the first two columns).

Housing tenure matters for energy expenditure in Table 3. Renters have lower energy expenditure when controlling for socioeconomic, housing, energy, and location variables. The magnitude in column (3) is approximately 11% lower spending. Energy expenditure is also lower for households where there is a mortgage, compared to households without a mortgage, with similar magnitudes to renters. These results suggest that the pressure for rent or mortgage repayments might lead to lower spending on energy. These coefficients likely reflect greater constraints for renters and borrowers with a mortgage which restrict energy expenditure and related investments.

There is a role for asset distributions in explaining energy expenditure in Table 3, although only the highest quintile (5) has statistical significance in each column. The results suggest a somewhat weak influence of the asset index, such that higher asset levels are associated with moderately higher energy consumption.

Scale variables have anticipated impacts in Table 3. There is larger energy expenditure for households with more occupants based on a variable using an OECD equivalence scale. There is also high energy expenditure when there is a larger change in this variable related to the number of occupants. Similar stories are evident for the dwelling size based on the number of bedrooms: as the number of bedrooms increases, there is greater energy expenditure. In column (3), an extra bedroom is associated with approximately 16% higher energy expenditure (exp [0.147]-1). Also, when there is an increase in the number of bedrooms between survey waves, energy expenditure is also higher. This could occur either through a home renovation or through moving dwellings.

There are negative coefficients for the solar panel variable in explaining energy expenditure in Table 3. The coefficient magnitudes suggest that having solar panels leads to lower electricity and gas expenditure by around 11%. This could occur through several channels, such as cost savings if households switch from using gas to heat water to electric heating using solar power, and other use of solar electricity in place of grid-supplied electricity.

Higher spending on each of the energy types in the earlier wave of 2021-22 is linked to higher energy spending changes for the latest survey wave of 2022-23 in column (1) of Table 3. In column (2) of Table 3, there are different relationships for some lagged energy expenditure variables because the dependent variable now is only the log of electricity and gas expenditure and does not include fuel oil or other energy types. As expected, there is a negative relationship between spending more on fuel oil in the earlier wave and electricity and gas expenditure in the later wave. This can be explained by users of oil from the previous wave continuing to do so in the later wave, meaning that greater oil expenditure can partially substitute for spending on electricity and gas.

There is also an interesting relationship for the change in oil expenditure in column (2) of Table 3 which effectively explains the change in electricity and gas expenditure. The negative and significant coefficient for the change in oil expenditure suggests that households who increased their oil expenditure, when controlling for their prior electricity and gas expenditure, also had lower electricity and gas expenditure in the later survey wave. This may indicate fuel switching, if higher oil use replaces some electricity and gas use, following price hikes for electricity and gas (substitution effect). The significant coefficient for oil expenditure change applies in both rural and urban areas, as evident in Appendix Tables A.2 and A.3.

Table 4 has three sets of results explaining the binary variable of having problems paying bills in the 2022-23 wave. The second column includes an additional detailed categorical variable for the household composition type, with combinations referring to gender, age, and numbers of adults or children. However, the results are very similar compared to column (1), which does not have this categorical variable, and the average variance inflation factor increases to 2.3 due to correlation between household size and composition (as evident in Appendix Table A.1). The first two columns control for whether the household experienced problems paying bills in the earlier wave (2021-22), meaning that the results give an indication of how this issue has changed between the two waves. The third column drops this lagged dependent variable (in the cross-sectional context) and so explains the level. While the adjusted R-squared is much lower when not controlling for the earlier problems paying bills, the narrative for the other explanatory variables is very similar.

The influence of being in the bottom income quintile is evident in Table 4. Higher income quintiles are generally less likely to experience problems paying bills. The coefficients for the top three income quintiles tend to be quite similar. The second income quintile is more similar to the bottom income quintile, based on columns (1) and (2), which effectively explain the change in energy-bill problems. However, there is a negative and significant coefficient in the final column which does not control for the earlier experience of problems paying bills. A larger

Table 4
Linear probability model results explaining problems paying bills.

	(1; Δ)	(2; Δ)	(3; level)
Ref: income quintile 1			
Income quintile 2	−0.006	−0.009	−0.029***
	(0.009)	(0.010)	(0.011)
Income quintile 3	−0.016*	−0.021**	−0.036***
	(0.009)	(0.010)	(0.012)
Income quintile 4	−0.024***	−0.025***	−0.052***
	(0.009)	(0.010)	(0.011)
Income quintile 5	−0.025**	−0.027**	−0.061***
	(0.010)	(0.011)	(0.013)
Quintile 5: change in income	−0.015**	−0.015**	−0.026***
	(0.006)	(0.006)	(0.008)
Renter	0.055***	0.039***	0.065***
	(0.009)	(0.008)	(0.009)
Mortgage	0.004	−0.013**	−0.025***
	(0.004)	(0.005)	(0.006)
Ref: asset quintile 1			
Asset quintile 2	−0.044***	−0.046***	−0.075***
	(0.013)	(0.013)	(0.015)
Asset quintile 3	−0.056***	−0.058***	−0.101***
	(0.012)	(0.012)	(0.013)
Asset quintile 4	−0.054***	−0.055***	−0.102***
	(0.012)	(0.012)	(0.013)
Asset quintile 5	−0.062***	−0.062***	−0.108***
	(0.012)	(0.012)	(0.014)
Occupants; equivalized	0.036***	0.041**	0.077***
	(0.007)	(0.020)	(0.027)
Change; occupants; equivalized	0.020	0.012	0.017
	(0.031)	(0.032)	(0.031)
Bedrooms	−0.000	0.000	−0.000
	(0.003)	(0.003)	(0.004)
Change; bedrooms	0.002	−0.001	0.001
	(0.008)	(0.008)	(0.008)
Solar panels	0.007	0.009	0.010
	(0.009)	(0.009)	(0.010)
No central heating	0.008	0.005	0.014
	(0.009)	(0.009)	(0.010)
Oil expenditure	0.007	0.007	0.010
	(0.006)	(0.005)	(0.007)
Change; oil expenditure	0.005	0.008	0.017
	(0.007)	(0.007)	(0.010)
Other energy expenditure	−0.026***	−0.021***	−0.025**
	(0.008)	(0.008)	(0.010)
Log electricity and gas spend	0.005	0.008	0.010*
	(0.006)	(0.006)	(0.006)
Problem paying bill	0.558***	0.542***	
	(0.028)	(0.028)	
Household composition controls	No	Yes	Yes
Adjusted R^2	0.359	0.371	0.159

Notes: There are 10′790 observations in each case. Locational controls, insignificant solar water heating, the survey month (24 possible months in 2021-22 plus a small 25th category for delayed interviews in early 2023), the gap between household interviews in months, a small category where tenure is not disclosed, and constants are not shown. Statistical significance is indicated by: *** (1%), ** (5%), and * (10%).

change in income also appears to help householders avoid problems paying bills, as there are negative and significant coefficients for the top income change quintile in each column. The magnitudes are two to three percentage points.

Housing tenure appears to be important for explaining problems paying bills, as there are positive and significant coefficients for the renting variable in Table 4. Renters are up to seven percentage points more likely to experience bill-paying problems, when explaining the level of these problems in column (3).

The renting influence on problems paying bills is more pronounced for low-asset households, rather than low-income households, as evident through extra interaction analysis in Appendix Tables A.4 and A.5. Problems paying bills for renters in the bottom asset quintile are more likely by between 12 and 17 percentage points when assessing both the change and the level, whereas the corresponding magnitudes for renters in the bottom income quintile are between four and six percentage points.

The asset index appears to be more important than income when explaining problems paying bills in Table 4. For instance, being in the second asset quintile reduces the likelihood of having bill-paying problems by 7.5 percentage points compared to being in the lowest asset quintile. The corresponding magnitude for the top asset quintile is 10.8 percentage points. These results relative to the bottom quintile suggest that bill-paying problems are heavily concentrated among the bottom asset quintile.

The number of occupants appears to be important for experience of problems paying bills. For the number of occupants (equivalized) increasing by one unit, there is an increase of around four percentage points in the first two columns which effectively explain the change in bill-paying problems. Even though there is substantial correlation between the household size (number of occupants) and extra household composition controls in column (2), the magnitude and significance for the number of occupants is quite similar to column (1).

Problems paying bills are likely to partly relate to higher spending, all else equal. The importance of energy spending is suggested in Table 4, although there is only significance at the 10% level in column (3) when explaining the level of the probability of experiencing bill-paying problems. There might be value in having diverse fuel sources, as there are negative and significant relationships between the amount spent on other fuel types and the probability of experiencing problems paying bills. This relationship is statistically significant at the 1% level in the first two columns (explaining changes) and at the 5% level in the final column (explaining the level).

Persistence is also a key characteristic of the experience of problems paying bills. Households who experienced this problem in the earlier wave were much more likely to have the same experience in the later wave. The magnitude is large at over 50 percentage points. The lagged variable for problems paying bills has substantially larger magnitudes than other indicator variables and has the lowest *p*-values, suggesting that persistence is a key issue.

Table 5 again assesses problems paying bills, but switches to a multinomial logit model with four dependent variable categories to compare influences on persistence or changes in bill-paying problems. The key findings of this multinomial logit model for potential changes in bill-paying problems in Table 5 relate to income, housing tenure, the asset index, the number of occupants, and fuel-switching potential.

Many of the marginal effects for income are statistically significant in Table 5. This is especially the case in relation to the first and last columns which show persistence of the bill-paying context. Compared to the reference of households with income in the lowest quintile, all other households are more likely to have had no reported problems in either survey wave and less likely to have had problems in both survey waves. While the magnitudes tend to get further away from zero as income increases, there are somewhat modest differences in magnitude across the income quintiles. From a distributional perspective, this indicates that being in the bottom income quintile is the main issue, while progressively being in a higher income quintile only has limited impact. For example, the marginal effect for being in the top income quintile is not statistically different compared to the middle-income quintile, with respect to persistently avoiding bill-paying problems.

Higher income also helps households avoid changing from no problems in 2021-22 to having a problem in 2022-23, as indicated by negative marginal effects in column (2) of Table 5. The key is again the lowest quintile, as quintiles 3-5 have a lower probability of newly experienced problems by around 1.3-1.5 percentage points.

Results with a continuous income variable in hundreds instead of the quintile variable help to assess continuous changes, as in Appendix Table A.6. This gives an indication of possible impacts of future subsidies of various sizes, given that household subsidies are often implicitly or explicitly like extra income. A one-unit (£100) change in income decreases the probability of having bill-paying problems in both survey waves by 0.08 percentage points (i.e. −0.0008). To reduce this

Table 5
Multinomial logit results explaining changes in bill paying problems; marginal effects.

	(1) No problems	(2) No:22; Yes:23	(3) Yes:22; No:23	(4) Problems: both
Ref: quintile 1				
Income quin. 2	0.033***	−0.002	−0.006	−0.024***
	(0.010)	(0.007)	(0.006)	(0.007)
Income quin. 3	0.035***	−0.013*	−0.007	−0.015*
	(0.011)	(0.007)	(0.006)	(0.008)
Income quin. 4	0.063***	−0.013*	−0.009	−0.041***
	(0.011)	(0.007)	(0.006)	(0.007)
Income quin. 5	0.072***	−0.015*	−0.016***	−0.041***
	(0.012)	(0.008)	(0.006)	(0.008)
Δ; income Q5	0.020***	−0.010**	−0.004	−0.007
	(0.008)	(0.004)	(0.003)	(0.006)
Renters	−0.113***	0.041***	0.018***	0.054***
	(0.010)	(0.007)	(0.005)	(0.006)
Mortgage	−0.031***	0.013**	0.005	0.013*
	(0.009)	(0.005)	(0.004)	(0.007)
Ref: quintile 1				
Asset quin. 2	0.035***	−0.015**	0.002	−0.022***
	(0.009)	(0.006)	(0.005)	(0.006)
Asset quin. 3	0.072***	−0.028***	−0.007	−0.038***
	(0.010)	(0.007)	(0.006)	(0.006)
Asset quin. 4	0.086***	−0.026***	−0.016***	−0.044***
	(0.010)	(0.007)	(0.005)	(0.006)
Asset quin. 5	0.096***	−0.039***	−0.020***	−0.037***
	(0.010)	(0.006)	(0.004)	(0.007)
Occupants	−0.075***	0.025***	0.018***	0.031***
	(0.007)	(0.004)	(0.003)	(0.004)
Δ; occupants	−0.011	−0.003	0.003	0.011
	(0.020)	(0.014)	(0.009)	(0.011)
Bedrooms	−0.001	−0.002	0.000	0.003
	(0.004)	(0.003)	(0.002)	(0.003)
Δ; bedrooms	−0.003	0.000	−0.002	0.005
	(0.008)	(0.006)	(0.003)	(0.005)
Solar panels	−0.006	0.009	−0.005	0.003
	(0.015)	(0.010)	(0.009)	(0.011)
No cen. heat	−0.022**	0.011*	0.008	0.003
	(0.009)	(0.007)	(0.005)	(0.006)
Oil spend	−0.014	0.008	−0.007	0.012*
	(0.011)	(0.006)	(0.007)	(0.007)
Δ; oil spend	−0.018	0.000	−0.003	0.021**
	(0.013)	(0.006)	(0.004)	(0.011)
Other spend	0.322***	−0.038	0.014	−0.299***
	(0.102)	(0.041)	(0.012)	(0.109)

Notes: The sample size is 13′249. Statistical significance: *** (1%), ** (5%), * (10%). Standard errors in brackets. Marginal effects are not shown for locational controls, insignificant solar water heating, the survey month (24 possible months in 2021-22 plus a small 25th category for delayed interviews in early 2023), the gap between household interviews in months, a small category where tenure is not disclosed, and the constant.

probability by 1 percentage point, an increase in income (or a subsidy of an equivalent size) of approximately £1200 would be required.

Income changes also help to explain changes or persistence in bill-paying problems in Table 5. Having a change in household income between 2021-22 and 2022-23, which is in the top quintile, is linked to a lower probability of changing from not experiencing bill-paying problems in 2021-22 to having bill-paying problems in 2022-23. The magnitude is one percentage point with significance at the 5% level. These households with income changes in the top quintile are also more likely to persistently avoid bill-paying problems, compared to households with income changes in the lower four quintiles.

The probability of having no bill-paying problems in 2021-22 but then having problems in 2022-23 is affected more by asset levels rather than income levels. Being in the highest income quintile rather than the lowest leads to a lower probability of this energy outcome by 1.5 percentage points. In contrast, the corresponding magnitude for the asset index is 3.9 percentage points.

Housing tenure has substantial influences on bill-paying problems, as depicted in Table 5. Both renters and households with a mortgage are more likely to persistently experience bill-paying problems, while being less likely to persistently avoid this problem. Renters are also more likely to change from no experience of bill-paying problems in 2021-22 to having problems in 2022-23, with a magnitude of four percentage points.

The number of occupants has substantial influences on bill-paying problems. For a one-unit increase in the equivalised number of occupants there is a higher probability of persistently experiencing bill-paying problems in column (4) with magnitude of 3.1 percentage points, and around eight percentage points lower probability for persistently having no problems in column (1). Households with a larger number of occupants are also more likely to transition from no problem to having a problem, with a magnitude of 2.5 percentage points for the one-unit occupant increase.

There are no significant marginal effects for having solar panels in Table 5. This could suggest that having solar panels might not have a major influence on a household's bill-paying problems, even though we found evidence of solar influences on reduced energy spending for Table 3. Several reasons may explain the non-significance for the solar panel variable. One is that solar-panel uptake may be too low among the households who are vulnerable to problems paying bills, especially where they are unable to afford the upfront cost of solar panels. It might also relate to the dependent variable covering types of bills beyond electricity (gas, water, telephone, other). In contrast, a dependent variable with only problems paying for electricity bills might show a stronger link. It is also possible that solar panels are genuinely not important for bill-paying problems, especially given the threshold nature of this variable; solar panels may not have a clear influence of tipping households over the line from problems to no problems. The solar findings in this paper are similar to studies of other countries, such as Australia and the US (Best and Sinha, 2021; Hammerle and Burke, 2022).

Fuel-switching opportunities might promote better contexts for bill-paying. As the spending on other types of domestic energy (not electricity, gas, or fuel oil) increases, households are more likely to persistently have no problems, and less likely to have persistent problems. The magnitudes relate to a one unit increase in the explanatory variable, which is spending on other energy in thousands. Converting this to a unit of pounds (not thousands), a one-pound increase in spending on other energy types in 2021-22 is associated with a higher probability of 0.03 percentage points of having no problems in both 2021-22 and 2022-23.

3.2. LOWESS

Further distributional insights are evident with LOWESS. Fig. 1 shows how electricity and gas expenditure vary across the income distribution. Expenditure generally increases with a close to linear trend across the income distribution. However, there is a steeper slope at the upper end of the income distribution. Households with income in the top quintile spend substantially more on electricity and gas than households with lower income. This aligns well with Table 3.

Similarities and differences are evident when comparing across years in Fig. 1. The slope and curvature of the distributions are similar across the three survey waves for 2020-21, 2021-22, and 2022-23. The later years have higher average expenditure, partly due to general inflation, as the distributions are in nominal expenditure terms. However, there is a noticeably larger shift up in the distribution for 2022-23, consistent with the energy price hikes which occurred in mid-2022 in the UK. As expected, the gap between 2021-22 and 2022-23 is slightly larger when dropping households where the 2021-22 interview was conducted after

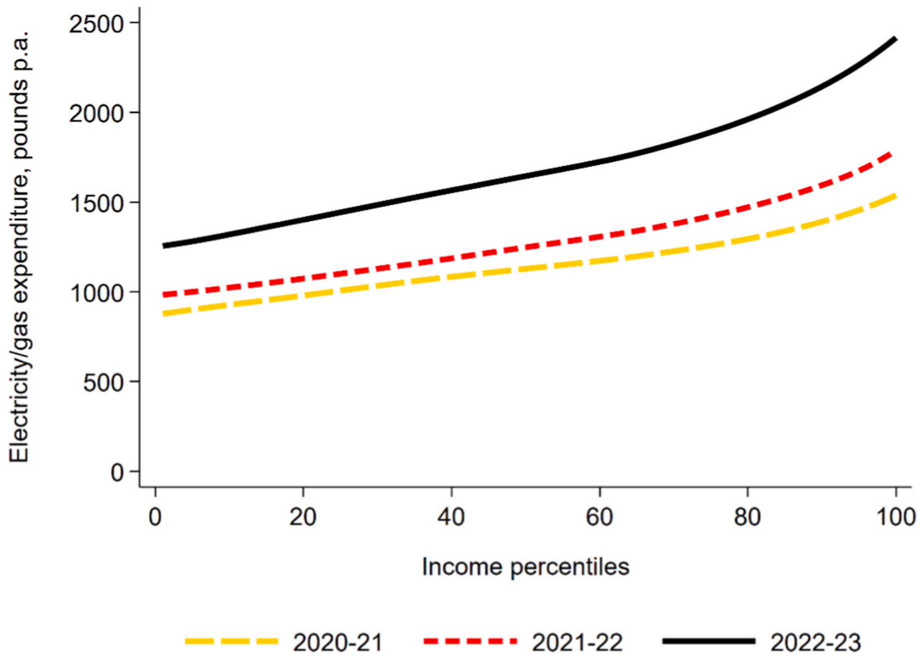

Fig. 1. Annual electricity and gas expenditure by income percentile and smoothed using LOWESS, based on 13′701, 12′800, and 16′841 households for 2020-21, 2021-22, and 2022-23, respectively. Data: University of Essex, Institute for Social and Economic Research ISER (2024).

April 2022, as inferred with Appendix Figure A.1 showing a lower 2021-22 line with the sub-sample. This accounts for the timing of the 2022 price hikes, which became prominent from April onwards (Office for National Statistics, 2022a). This implies that our results are conservative, since restricting analysis to only households interviewed before April 2022 would lead to a larger gap. We also show a scatterplot in Appendix Figure A.2, although it is difficult to discern a pattern based on the relatively large number of observations (with overlapping points) and considerable variation in electricity expenditure.

The probability of having problems paying bills declines as income increases in Fig. 2. The smoothed distribution is close to linear, with some exceptions. A key exception is that the lowest quintile for household income appear to be particularly affected by problems paying bills. This is evident with the slope of the distribution being steepest at the left end of the distribution, where the probability is highest.

The large energy price hikes in 2022 appear to be evident in Fig. 2 distributions. The distributions for problems paying bills were quite similar for 2020-21 and 2021-22. The later wave has a slightly higher range of values, with the difference primarily at low values for income. When considering 2022-23, there is a larger shift up in the probability distribution, just as it was shown for energy expenditures in Fig. 1. This shift is modest for the highest two income quintiles. However, there

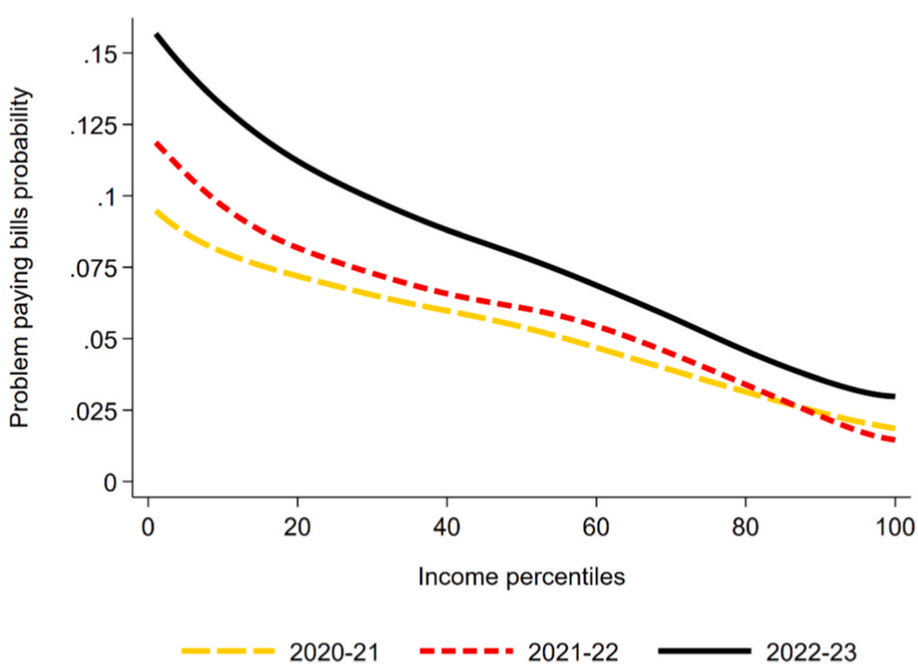

Fig. 2. Problem paying bills by income percentile and smoothed using LOWESS, based on 16′768, 16′059, and 21′270 households for 2020-21, 2021-22, and 2022-23, respectively. Data: University of Essex, Institute for Social and Economic Research ISER (2024).

appears to be larger shifts up for the lower three income quintiles, suggesting that impacts of the energy price hikes may have been widespread across a substantial proportion of UK society.

We also produce similar figures with bandwidths of 50% and 90%, to check robustness around the bandwidth of 80% used above. As expected, the 50% bandwidth gives slightly less smoothed outcomes, but maintaining similarity to Figs. 1 and 2. The 90% bandwidth gives almost identical outcomes compared to the 80% bandwidth. These extra figures are to be found in the Appendix (Figures A.3-A.6).

3.3. Limitations

Common limitations related to econometric studies include potential omitted variable bias and reverse causation, which can sometimes be addressed to a greater extent with panel regressions incorporating temporal variation. Future studies could therefore investigate similar issues with extensive panels. However, there are several reasons why this may not add substantial value compared to our current approach. One reason is that our analysis already incorporates temporal variation, through using changes in key explanatory variables, and lagged dependent variables in a cross-sectional context, to imply that we can explain changes in the dependent variable. Another reason is that persistence is a defining characteristic which is evident in our results, with prior experience of problems paying bills having a very strong link to subsequent experiences. In addition, panel approaches may struggle to deal with variation which is both time-varying and heterogeneous across households. Future research could therefore further consider cross-sectional variation with detailed distributional analysis.

Longitudinal tracking is a further issue, as the survey tracks the responding person over time, and these respondents may be part of different households in different waves. Future data collection and research may therefore benefit from greater focus on following consistent households over time. However, this is not likely to be a major limitation for our study for several reasons. One is that our LOWESS analysis does not use longitudinal tracking. For our regression analysis which does rely on longitudinal tracking, we focus only on two waves, on either side of the price hikes linked to geopolitical fragmentation. It is unlikely that there would be a substantial number of household changes between these two adjacent waves. We also control for the change in the number of occupants, and the change in household income. These controls should at least partly account for the small number of household composition changes.

The different timing of the survey interviews for different households may initially appear to be a limitation. The 2021-22 wave includes interviews across each of the 24 months plus some delayed interviews in early 2023. However, we control for this in our regressions with 24 binary variables relative to a 25th reference category. Our main LOWESS analysis is conservative by including households from the 2021-22 wave who were surveyed after average prices started to rise quickly in April 2022. We also note that having all households surveyed on the same date would have limited additional benefit in our context, as price rises experienced by households occur at different times anyway depending on their individual circumstances (e.g. whether they are on a fixed or variable tariff, when fixed tariffs end, whether they switch providers, or whether they switch contracts with the same provider).

A challenge in our context is that most UK households have a combined electricity and gas bill, and the survey reports combined expenditure in these cases. However, we produce similar robustness results such as positive influences related to income, the asset index, scale variables, and persistence when explaining an electricity-only dependent variable (Appendix Table A.7) for a smaller subset of households which has separate electricity and gas bills (including households not using gas).

4. Conclusion and policy implications

4.1. Policy implications

Our results highlight the persistence of the challenges facing policymakers. While the energy price hikes following geopolitical fragmentation highlight an issue with intensifying and broadening impacts across larger proportions of society, the underlying energy challenges also existed prior to these price hikes. If policymakers can address household energy issues in equitable and cost-effective ways, this can be informative for dealing with future price hikes, and other countries including developing countries.

A key policy implication from this paper is the importance for specific consideration of economic distributions. Our findings suggest that the bottom income quintile was substantially different to other quintiles with respect to bill-paying problems. The context for energy consumption was somewhat similar in this regard. These results suggest that the bottom 20 to 30% of households should be the primary target for policymakers seeking to improve household energy outcomes in an equitable and cost-effective way.

When considering policy targeting across economic distributions, policymakers should consider assets more and not just income. Our results show strong links between assets and household energy outcomes. Assets have been used in some countries historically for various means-tested programs, and should be a feasible alternative for policymakers in some contexts. There are potential benefits of using assets to determine policy support related to lower influences on behavioural incentives and greater potential to address broader inequality. Incentives to lower assets to get more support from policymakers may not be a widespread issue. In contrast, income means testing may influence the incentive to work and gain income.

Our results also inform possibilities related to energy investments or behaviour. The influence of solar panels in reducing energy consumption suggests that policymaker support for solar panels could lower household energy expenditure. However, the solar influences for energy consumption were modest in this paper and missing for bill-paying problems. Policymakers could therefore take a cautious approach to subsidising solar panels or other energy investments. Our results also suggest that fuel switching might help with reducing electricity and gas expenditure. However, the broader implications of other fuels should be considered beyond expenditure influences, including environmental or health implications of fossil fuels or biomass. Energy efficiency investments are a further possibility.

Housing tenure is another key issue for policy design. Our results show a large influence of renting in raising the probability of bill-paying problems. Renters with low asset levels were found to be particularly more likely to face problems paying bills. The results may justify greater support for renters related to energy aspects, especially those with low asset levels. Either cash or investment support is possible, with longer-term potential from investments. However, split incentive challenges (such as the landlord-tenant dilemma) mean that policy design needs to be carefully targeted. For example, it can be difficult to provide support for energy investments which has a net benefit to renters, after considering the possibility that landlords may raise rents for housing with better energy investments.

Policy design may also consider further ways to address persistence in bill-paying problems. As our results show prior bill-paying problems leading to continued problems, and higher subsequent energy expenditure, there may be justification for educational or behavioural approaches. Educational approaches might include increased focus on financial literacy, although this is not something that our empirical analysis has investigated. Behavioural approaches might be based on information to guide better energy choices, such as energy-saving habits.

4.2. Future research

Future research may evaluate the many policies introduced by governments after energy price hikes. Other data sources would be better suited to evaluation studies, compared to the UK Understanding Society survey which has interviews spread across the months of the survey waves. It would also be difficult for any evaluations to precisely untangle the many UK policy changes introduced in rapid succession in 2022-23. Our contributions instead seek to inform forward-looking policy design for several reasons. We note that energy expenditure and problems paying bills have been longstanding issues; the geopolitical events from 2022 further intensified these issues. Temporary policies introduced to rapidly address price shocks likely avoided some potential fuel poverty, but we still found elevated bill-paying problems. There is also potential to improve equity and efficiency of policy design through new approaches, such as with consideration of new policy approaches discussed in Section 4.1.

CRediT authorship contribution statement

Rohan Best: Writing – original draft, Visualization, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Reinhard Madlener:** Writing – review & editing, Visualization, Validation, Resources, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Funding from Macquarie University supported travel for Rohan Best in 2025; this research was partly undertaken at this time.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2026.115260.

Data availability

The authors do not have permission to share data.

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