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Original research article

Using smart energy meter data to design better policy: Prepayment meter customers, fuel poverty and policy targeting in Great Britain

Tina Fawcett [a,*], Jason Palmer [b], Nicola Terry [b], Brenda Boardman [a], Uttara Narayan [a]

[a] Environmental Change Institute, University of Oxford, South Parks Road, Oxford OX1 3QY, UK
[b] Cambridge Architectural Research Ltd, 25 Gwydir Street #6, Cambridge CB1 2LG, UK

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ABSTRACT

During winter 2022–23, residential energy prices were exceptionally high in Europe. Governments provided unprecedented energy support payments, but millions of households still suffered from inadequate access to energy. This paper uses gas and electricity smart meter data from 2019 to 20 to 2022–23 for 11,500 prepayment meter (PPM) customers in Great Britain to characterise energy use over time, by dwelling and household characteristics, examine the effects of high prices and cold weather, evaluate current policy and propose improvements. Households with PPMs are a group where fuel poverty is highly concentrated. This sample use less energy than the general population and 63 % self-disconnected at least once a year, with an annual average 28 h of disconnection. Using smart meter data has enabled identification of groups in extreme need: 7 % of households use scarcely any energy, and no gas, for heating; 4 % self-disconnect for at least 240 h per year. More homes self-disconnected from gas during cold periods than at other times, despite the greater need for heating. The paper proposes replacing the current 'Cold Weather Payment' policy that has proven ineffective with advance, daily payments directly to energy accounts that are triggered by forecasts of minimum temperatures of −4 °C. High prices in 2022–23 had a very significant effect: annual gas use per household fell by 20 %, while electricity use fell by 3 %, compared with 2019–20. A new Energy Cost Support Scheme is proposed to provide financial support for households in fuel poverty, worth about £1000 per household. For the longer term, smart meter data could enable better targeting of support for vulnerable households and the fuel poor.

1. Introduction

During winter 2022/23, residential energy prices were exceptionally high in Europe. Household energy bills increased significantly due to factors including an increased global demand for gas following the pandemic and later, the impact of Russia's invasion of Ukraine on energy markets. In the UK, average annual household bills for gas and electricity increased from £1277 in winter 2021/22 to £3549 in October–December 2022 and £4279 by January–March 2023 [1]. The government responded by subsidising prices for all households, and similar decisions were made across Europe, where governments provided unprecedented energy support payments. Despite the huge expenditure of public money, many millions of households still suffered from inadequate access to energy and had to 'self-ration' their use of energy [55].

This paper concentrates on the experiences of households in Great Britain (includes households from England, Wales and Scotland, not Northern Ireland) with prepayment meters prior to and during the 2022/23 energy price crisis. These households are known to be a group where fuel poverty is highly concentrated [2]. Evidence from this group is likely to be a good indicator of the problems faced by many people coping with fuel poverty. To date, prepayment meter households have been overlooked in terms of research focus and policy attention. The research is based on data from households with smart prepayment meters for both electricity and gas who are customers of Utilita, a medium-sized energy retailer.

Smart meter data has enabled generation of new insights: using energy data from four years, up to 2022/23, this analysis examines how prevalence, frequency and duration of self-disconnections, and energy use, have varied with external temperature, price, and dwelling and household characteristics. There is also analysis of how different policies and targeted payments have affected energy use and self-disconnection –

* Corresponding author.
E-mail addresses: Tina.fawcett@eci.ox.ac.uk (T. Fawcett), jason.palmer@carltd.com (J. Palmer), Nicola.terry@carltd.com (N. Terry), Brenda.boardman@ouce.ox.ac.uk (B. Boardman), Uttara.narayan@ouce.ox.ac.uk (U. Narayan).

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giving insights into how future policy should be designed. Findings from prepayment meter users are used to propose policy reforms for people facing fuel poverty in general. Energy prices for future years are expected to be higher than in recent years, albeit hopefully not as high as in 2022/23 [3]. Therefore, understanding how governments could better target support to those in greatest need, and the minimum level of support needed to prevent serious suffering, is important for the future.

2. Literature review

2.1. Prepayment meters

Prepayment energy metering is where customers must make payments or have credit before they can use energy. Prepayment meter (PPM) technology is most prevalent in South Africa and Great Britain [4]. Other countries which have trialled or installed PPMs in the past two decades include the USA, China, Argentina, Brazil, India, Turkey, Northern Ireland, New Zealand, Australia, Ghana, Kenya, Rwanda, and Mozambique [4] [5]. In 2016, there were approximately 22 million PPMs installed globally, for both gas and electricity billing [6].

Around 15 % of households in Great Britain (>4 million households) have one or more PPM. According to government data, in 2023, there were 4.14 million prepayment electricity meters in England, Wales and Scotland, of which 2.2 million were smart, and 1.94 million were traditional or legacy meters [7]. Analysis based on data from Ofgem, the energy regulator for Great Britain, suggests there were 3.27 million gas PPMs at the end of 2022 [8]. PPMs can either be chosen voluntarily by customers or installed at the request of their energy company to repay customers' debts. Concerns about ‘forced’ installation of traditional PPMs in winter 2022–23 led to Ofgem imposing a temporary moratorium on new installations for particular households, such as those with health conditions that require uninterrupted energy, not having the capacity to top-up the meter, or those above 85 years [9].

PPMs can be useful to budget and control energy-related expenditure, to avoid going into debt, or to pay back a debt to the energy company over a manageable period. A nationally representative poll of PPM customers showed that 86 % of customers chose this method of payment [10]. In general, a PPM can facilitate repaying a debt over a longer period of time than would be typical for credit customers [11]. However, this pay-as-you-go method means that households experience significant seasonal variations in energy expenditure, particularly for gas which is the main heating fuel (this also applies to household paying by standard credit, rather than by a fixed monthly direct debit [12]).

A longstanding criticism of PPMs is that customers who run out of credit are allowed to ‘self-disconnect’ from their energy supply. Ofgem defines self-disconnection as an event which “occurs when customers experience interruption to their gas or electricity due to lack of credit on their prepayment meters.” [13] . This can transfer the burden of decision-making on disconnecting on to the poorest households, thereby removing the accountability of energy companies and render invisible the challenges of self-disconnections [14]. As noted by Citizens Advice, a UK-based consumer support organisation that provides various forms of consumer advice–“*PPMs simply pass off the responsibility for disconnection from energy suppliers to consumers - but the end result is the same. It's time to recognise self-disconnection for what it really is – disconnection of an essential for life service.*” [15] (2023:13). Self-disconnection is a key focus of this paper's empirical research.

The UK has ‘effectively banned’ disconnection of household energy supply by energy companies [15]. In 2018, 6 disconnections for debt were observed in comparison to 640 in 2013, just under 30,000 in 1998 and 176,000 in 1975 [16] [13]. However, rates of self-disconnection from PPMs are significant. A UK-representative 2023 survey found that 33 % of people reported at least one self-disconnection in the previous year and 19 % of them had disconnected for >24 h, at least once [15]. A different estimate using Ofgem data for ‘any’ disconnections [17], suggests the percentage of smart PPM customers experiencing at least one self-disconnection per quarter was 18–28 % for electricity and 16–35 % for gas in the quarters Q4 2021 – Q2 2023. According to Citizens Advice, Ofgem's assessment of rates of self-disconnection is incomplete and underestimated [18].

Self-disconnections can have serious impacts on mental and physical health. 63 % of UK PPM customers who had disconnected in the last year said it had negatively impacted their mental health [15]. Nearly half of them (47 %) also reported a negative impact on their physical health—households with disabilities and long-term health conditions were particularly vulnerable. This is not just a British phenomenon: in Australia, where PPMs are primarily deployed in indigenous communities, there are concerns around lack of access to cooling resulting in heat-related mortality. [5,19] [20].

There are other disadvantages of PPMs. UK PPM customers have historically paid more per unit of energy than credit or debit customers [21]. However, from 1 July 2023, the government guaranteed that both price caps will be equalised [22]. Difficulties of topping up meters with credit can also be serious, with traditional, non-smart PPM users being unable to top-up when shops or sources of energy credit are not open. Smart meters allow for more convenient and remote means of paying. Ofgem, has also mandated ‘friendly credit’ periods in the evenings and during weekends where PPM customers are kept on supply, with a short-term loan, if they have run out of credit on their meter.

Empirical research suggests that despite their drawbacks, customers value the sense of control over their budgets and energy use that is provided by PPMs [23] [6,24].

2.2. Fuel poverty

Fuel poverty is highly concentrated among households with PPMs [24]. Fuel poverty arises when households cannot afford to pay for basic energy services for heating, hot water, cooking, lights and appliances. In England, PPM customers' rates of fuel poverty are almost three times higher than for those paying by direct debit (gas – 27.2 % PPM, 9.7 % direct debit, electricity – 27.8 % PPM, 10.5 % direct debit) in 2022 [2]. A 2022 survey representative for Great Britain 2022 found that among those who reported difficulty in affording their energy, 72 % were PPM customers as compared to 42 % who paid by other means [25].

As a phenomenon, fuel poverty results from a combination of low income, the energy requirements and efficiencies of homes and heating equipment, and the cost of energy [16]. Research in 2022 showed 55 % of UK PPM households are in receipt of a means-tested benefit, that is money given to support those on low incomes [26]. Fuel poverty has been recognised as a concept for over 40 years, being the focus of activism since the 1970s [27]. The impact of cold housing on health and the stresses brought on by living in fuel poverty have been long recognised by researchers, medical professionals and policy makers [28]. However, fuel poverty is far from being eradicated; even before the price rises, in 2021, 13.1 % of English households (3.16 million) were fuel poor, according to the government's definition [29].

The UK has used three different definitions of fuel poverty within the past ten years. The earliest definition was based on Boardman's work [16,30], whereby households who needed to spend 10 % or more of their net income to have adequate energy services were defined as being in fuel poverty. Between 2010 and 2015 the UK government commissioned a review of fuel poverty policy, which proposed a new definition [31]. This was the ‘low income high cost’ measure: a household is fuel poor if it has lower than average income, and higher than average fuel costs. In England, the government further revised the definition of fuel poverty in 2021 to ‘Low Income Low Energy Efficiency’ (LILEE), whereby a household is fuel poor if they are living in a property with an energy efficiency rating of band D, E, F or G, and their disposable income is below the poverty line [32]. There are now different definitions in use in the different countries making up the UK, complicating matters further. Importantly for policy purposes, none of these enables an address-specific identification of the fuel poor either on the basis of income, means-tested benefits, or the energy efficiency of homes. The difficulties of targeting support to the fuel poor have long been acknowledged, despite there being a need for additional support [33].

Debates around defining fuel poverty remain important at the national and EU levels, as the definition is critical to deciding on the nature of the challenge, its scale, and effective targeting and policy formulation [34] [12]. The UK's Department of Energy Security and Net Zero's (DESNZ) projections for 2023 indicate that an estimated 8.8 million households in England would be in fuel poverty under the 10 % definition on a 'before housing costs' definition of income and 12 million on an 'after housing costs' basis [32], as compared to 3.5 million households based on the LILEE definition [2]. The definition used can change the numbers of households estimated to be in fuel poverty almost fourfold. Independent analysis using the 10 % definition suggested that 65 % of all UK households were fuel poor in April 2023 - that is 18 million households [33]. Different definitions also change the geographical distribution of fuel poverty and the social characteristics of those vulnerable to it [35].

The choice of definition can be understood as political in nature [36], and definitions fulfil specific purposes and focus on particular causes of fuel poverty [12]. The current English LILEE definition is primarily a measure of progress against the government's fuel poverty target, rather than an estimate of the number of households who find it difficult to keep their homes warm, well-lit, provide sufficient hot water and run appliances [32]. Data presented subsequently will demonstrate that the English LILEE definition considerably underestimates the number of households with inadequate energy services. New definitions of fuel poverty have been proposed, to address various shortcomings of the current options [37,38].

2.3. Smart meter data

This paper uses smart meter data to generate insights about energy use, self-disconnection and the effectiveness of policy. Smart meter data for all types of households is made available via the Smart Energy Research Lab (SERL), a research resource which consists of smart meter and contextual data from approximately 13,000 homes that are broadly representative of the population in Great Britain in terms of region and Index of Multiple Deprivation quintile [39]. SERL data has been used, for example, to look at the impact of COVID on energy use patterns [40]. Unfortunately, PPM users are considerably under-represented in SERL [41]. The Energy Demand Observatory and Laboratory, a project linked to SERL, will seek to increase the representation of PPM households (www.edol.ac.uk).

There is growing interest in using smart meter data to alleviate fuel poverty, [42]. Smart meter PPM data has been used in an exploratory project to facilitate better identification and targeting of fuel poor households, with methods under development [43]. However, such use of smart data is in its infancy.

3. Policy context for Great Britain

The research in this paper results in specific policy recommendations for Great Britain. For context, selected policies related to rising energy prices and vulnerability to fuel poverty are outlined. There are four main schemes that provide additional energy-related income support (Table 1), most of which are based on means-tested benefits (MTBs). For a more comprehensive account of policy related to fuel poverty in Great Britain and its individual countries see [32]. Additional 'Cost of Living' payments have been made to around 8 million households receiving MTBs and all pensioners since 2022 [44]. They are not included in Table 1, because the focus is on policies that support directly with energy expenditure. Importantly, many MTBs are under-claimed [45], so any targeting system based on means-tested benefits misses households in need.

The dramatic rise in prices in winter 2022/23 is illustrated by the increase in Ofgem's 'energy price cap', which is communicated as a cap on annual costs of gas and electricity for an average household (Fig. 1). The cap is actually a maximum cost per kWh, and many households (who consume above the average) pay more than the average annual cost [46]. The energy cap in Q1 2024 is almost double the amount it was in Q4 2020 (figures not adjusted for inflation). The predictions of energy analysts are that UK energy prices will stay relatively high at least until 2030 [3].

To reduce the impact of energy price rises, the UK government introduced the Energy Price Guarantee on 1st October 2022, designed to be a temporary, additional measure to protect consumers (Table 2). With typical household energy bills capped at £2500, the government provided a further £400 to every household in the UK, through the Energy Bills Support Scheme. There were additional schemes for businesses and to support users of other fuels, see [47] for details. The government's current estimate of the schemes' cost is £69 billion, of which almost £50 billion was spent on the Energy Bills Support Scheme and Energy Price Guarantee [47].

No additional financial support was announced or made available for winter 2023/24, sparking considerable concern for vulnerable households. Support proposals from campaign groups, think tanks and academics included universal basic energy provisioning, social tariffs, a national energy guarantee [48] as well as wider energy market reform recommendations such as the Green Power Pool [49]. Fuel Poverty Action proposed a free fuel allowance for all households, regardless of whether they are in fuel poverty [50]. The New Economics Foundation recommended a basic allowance of 1050 kWh of electricity and 2700 kWh of gas [51]. These proposals would take some time to introduce, whereas the recommendations in this paper were developed for immediate deployment in winter 2023/24.

4. Methods and data

Data was provided by Utilita, the UK's eighth largest domestic energy supplier, and initial analysis was published via a report [52]. Utilita specialises in offering a smart-enabled prepayment service to 720,000 of its 760,000 customers. In the UK, 57 % of all electricity and gas meters were smart (32.4 million out of 57.1 million) by the end of March 2023 [53]. Utilita's PPM customers can pay via a local store, through a phone app, by calling or their website. In addition, they can easily access an interest-free 'Power Up' loan. About two-thirds of payments are made via the app, website or by telephone.

Utilita provided data on a random sample of dual fuel, i.e. gas and electricity, PPM customers, intended to be representative of their customer base, over the period from January 2019 to May 2023. However, the sample was stratified to ensure adequate representation of population characteristics of interest and was chosen to have a minimum of at least 100 households in each Energy Performance Certificate grade from B to G, and each customer age band, and receiving the Warm Home Discount, and being on the Priority Services Register.[1]

Energy Performance Certificates (EPCs) report the energy efficiency of dwellings on a scale from A to G and have been mandatory at the point of sale or rental since 2007/8. This means the sample is biased towards dwellings that have changed hands since then. The effect for the Utilita sample is that younger customers (18–40 years old) are over-represented, compared with their total customer base. There may also be a skew towards more energy-efficient properties because re-letting or

[1] The register is a free service which means households get advance warning of scheduled power cuts, priority support in an emergency and other types of support [54] Ofgem, Get help from your supplier - Priority Services Register, 2023. (Accessed 1/12/232023). It includes households under several categories, those of state pension age, those disabled or who have a long-term illness, have young children or need to use medical equipment that requires an energy supply.

Table 1
Summary of ongoing energy-related income support measures.

Name of scheme	Countries	Amount	Eligibility	Payment type
Cold Weather Payment	England, Wales and Northern Ireland	£25 per week	People on certain MTBs, paid after a week of weather below 0 °C	Automatic, paid to bank accounts, within 14 working days of the cold weather event.
Winter Heating Payment	Scotland	£50 annually	People on certain MTBs	Automatic, paid to bank accounts
Warm Home Discount	Great Britain	£150 annually in 2022	People on certain MTBs, 2.2 million recipients in 2022	Discount on electricity bills, PPM credit / voucher. Automatic in England and Wales, by application in Scotland
Winter Fuel Payments	Whole UK	£150–300 annually	All pensioners, 11.3 million in Great Britain, 2021–22	Automatic, paid to bank accounts

Source: www.gov.uk

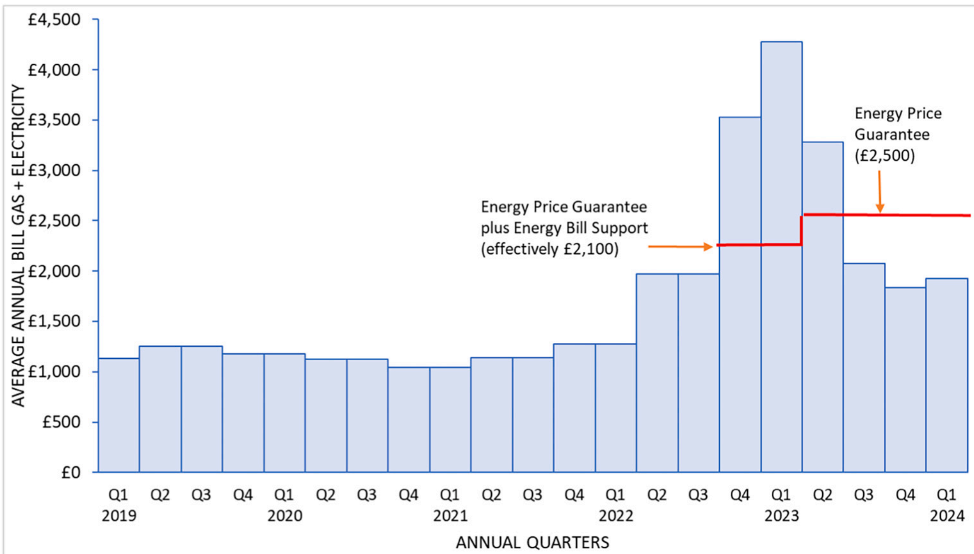

Fig. 1. Ofgem price cap for average gas and electricity dual fuel customers, Great Britain, by quarter, Q1 2019 – Q1 2024 (nominal prices, not inflation-adjusted). Source: [1]

Table 2
Additional energy price support, 2022/23, all Great British households.

Name of scheme	Amount	Nature of support
Energy Price Guarantee (EPG)	From 1st October 2022 till 30th June 2023: Limited Energy Price Cap to £2500 per annum in Great Britain, £2100 in Northern Ireland	From 1st October 2022, customers faced lower than market price unit costs per kWh of gas and electricity, either through discounted bills or via meters. From 1st July 2023, only PPM customers in GB received a per kWh EPG discount until 30th September 2023, and from then until 31st March 2024, a per day discount on their standing charges.
Energy Bills Support Scheme (EBSS)	£400	Paid via six monthly payments directly to bills / smart electricity PPMs from October 2022 to March 2023. Traditional PPM customers got vouchers by post, 13 % of which were still not redeemed by October 2023 [7].

Source: [47].

purchasing a property is often a trigger to carry out maintenance and/or improve energy efficiency.

Initially, data was provided for 28,728 customers. All data was provided anonymously, from customers who had given appropriate permissions, and its use was controlled through a data sharing agreement. Excluding customers without at least a whole heating season of data (October to March) reduced the sample to 14,406. Records were also excluded where there were either no energy data (likely due to lack of sharing permission) or >50 days or 10 % of days of missing data or zero energy use for either meter. The exclusion of homes with this proportion of zero energy use days, removed those only partially occupied for any reason, including use as holiday homes. This reduced the sample size to 11,519. Of these, there were 9800 customers in the first heating season, 9900 in the second, 9300 in the third, and 8800 in the last. 7600 are available in all four heating seasons.

The data include:

- Daily consumption of electricity and gas, split into night-time (11 pm-6 am) and day-time
- amount of credit on each meter at the start of the day, with the value and type of top-ups daily
- self-disconnection events, time and duration
- gas and electricity tariff details
- whether customers are on the Priority Services Register or receive the Warm Home Discount, and age band
- grid supply point, identifying geographical region
- EPC data for almost all homes (97 %), including total floor area, property type.

There is no data on income levels, the number of people living in each home, or whether there are children or people with disabilities in the household.

For this research, any self-disconnection which lasts >5 min is counted as a disconnection event. Fig. 2 shows the proportion of households with disconnections of various minimum lengths; choosing a definition of 5 min gives very similar results as choosing 30 min in terms of percentage of households affected.

From December 2020, Ofgem has required utilities to offer periods, known as friendly credit during weekends and overnight, so that customers cannot self-disconnect. It also requires offers of extra credit to PPM customers in vulnerable situations who have self-disconnected or self-rationed [55]. The aim was to deliver a sustained reduction in the number of PPM customers self-disconnecting. The friendly credit period varies between suppliers. Utilita's friendly credit hours are from 2 pm to 10 am the next day on weekdays and all day on Saturdays and Sundays, leaving a short 4-h day-time period on weekdays when households could experience self-disconnection.

The fall in percentage of households disconnecting between 2019/20 and 2020/21 is likely due to the introduction of friendly credit, which was implemented by Utilita before the Ofgem deadline.

5. Results

Note that all annual data is presented for years from 1 May (in year 1) to 30 April (in year 2). The heating season is defined as the six months October – March, following typical national heating patterns [56].

5.1. Customer attributes

Fig. 3 shows the age profile of the Utilita sample compared with average age in England and Wales for 2021. Although these are not exactly comparable statistics – those under 25 years are less likely to be energy company customers as they are less likely to head households – it indicates that this customer sample is younger than the general population, with a high proportion of 30 to 44 year olds.

The mean and median home size are both 74 m^2. This is significantly smaller than the mean size across all dwellings in England (97m^2), but larger than the mean size for social housing (67m^2) [58].

Table 3 below shows the proportions of homes by EPC grade. The first and last years' grade are included, as EPC ratings can change: roughly 11 % of homes changed rating over the period. The distribution is similar to the English housing stock, with slightly more homes at both ends of the range (A/B and E/F/G).

One third (34 %) of Utilita customers are on the PSR, this compares with an estimated national figure of one quarter (24 %) for 2022 (based on data from [2,60]). Warm Homes Discount is received by 29 % of Utilita customers, about three times the proportion in the general population (Table 1).

The location of customers by region (Table 4) shows that the North of England is over-represented, while the South and Scotland are strongly under-represented compared with national population data [57].

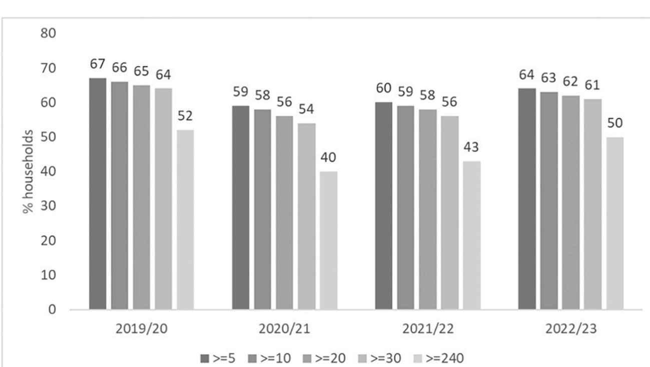

Fig. 2. Percentage of households who experienced at least one self-disconnection per year by year and by minimum length (in minutes).

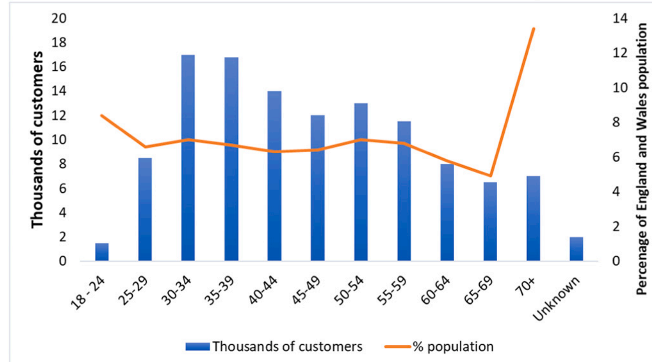

Fig. 3. Distribution of customers by age in comparison to the population of England and Wales
Sample size: 11,500 homes, Population data source: [57].

Table 3
Distribution of homes by EPC grade, Utilita and English housing stock (percentage).

	Number of cases (Utilita)	A/B	C	D	E	F/G
Utilita 2019/20	10,260	3.9	41.2	40.8	11.8	2.1
Utilita 2022/23	11,100	3.3	45.8	40.6	9.3	1.1
English housing stock, 2021	n/a	3.0	44.5	42.7	7.1	2.7

Sample size: 11,500 homes, English housing stock source: [59].

Table 4
Customers by region (percentage of total).

Region	Percentage	Region	Percentage
North West	23 %	South	6 %
Yorkshire	15 %	Western	5 %
North East	14 %	South West	4 %
South East	13 %	Eastern	3 %
Midlands West	10 %	East Coast	1 %
Midlands East	6 %	Other	0 %

Sample size: 11,500 homes.

The 12 regions serviced by Utilita map onto nine weather regions [61]. Table 5 shows mean degree days which is a measure of the total heating requirement over the year, and mean winter temperature. These are average figures across all regions, weighted by population in the Utilita sample. (The distribution of heating days and mean winter temperatures across the regions is available in [52].)

[56]. A comparison with national degree day figures using government data [62], shows <2 % difference in any year. The coldest year was 2020/21, and 2021/22 was the warmest.

To summarise, these households differ from the population in Great Britain: they are younger, occupy smaller homes, and are more likely to be in receipt of MTBs and Warm Homes Discount, and mostly live in England. Because of their age, these households are likely to contain more children than average.

Table 5
Average heating season (October – March) degree days and external temperature.

Year	Mean degree days	Mean winter temperature (°C)
2019/20	1520	7.0
2020/21	1610	6.5
2021/22	1400	7.7
2022/23	1460	7.3

5.2. Energy consumption and expenditure

Fig. 4 shows how mean annual gas and electricity consumption changed over the study period. All data is presented without temperature correction, as methods can be complex and contested [63].

In 2022/23, gas use was 19.9 % lower than 2019/20, while electricity use was 3.4 % lower. The years 2019–20 and 2022–23 are used for comparison because 2019–20 was pre-wholesale energy price rises, was not substantially within the pandemic period and had similar winter temperatures to 2022–23. 2019/20 included around five weeks of COVID-19 lockdown (where schools and many workplaces were shut, and people were only allowed to leave their homes for essential purposes [64]), only one of which was in the heating season. [63].

There were much longer periods of lockdown in 2020/21: seven months (March–June 2020, November 2020, January–March 2021) including four months during the heating season . Inevitably, this meant most people spent more time at home, and this was likely to have strongly influenced the increase in energy use in 2020/21, particularly gas, in addition to the colder temperatures. [65]

For comparison, a study which investigated gas and electricity use for October 2022 – March 2023, using smart meter data for 5594 households, very few of whom had PPMs, and comparing actual energy use with expected energy use if conditions in winter 2022/23 had been the same as in 2021/21, suggested that median electricity use reduced by 8.4 % and median gas use reduced by 10.8 % [66].

National data for calendar years (Table 6), in comparison with Fig. 4, indicates that Utilita households use less gas and electricity than the national average.

Fig. 5 indicates how average annual energy use shown in Fig. 4 varies between customers. The vertical bars on the charts show the range that includes 90 % of customers. Means (horizontal lines) are slightly greater than medians (blue dots). The ranges are large, indicating high variation between households especially for gas. The bottom range of gas use, given that this is the heating fuel, is very low. Note that showing data for 90 % of customers has excluded both unusually high and low figures (potential ‘outliers’). This ensures cautious interpretation of the range of energy consumption and expenditure.

Fig. 6 shows energy payments, separately for gas and electricity. These figures are actual expenditure for each year and have not been adjusted for inflation. The vertical bars, which includes 90 % of customers, show there is a wide range of above-average expenditure. In all cases, means are slightly greater than medians. The mean expenditures were £480, £460, £530 and £950 for gas and £680, £710, £800 and £1180 for electricity. Expenditure includes payments that are credited to the meter, i.e. the Warm Home Discount that was received by some each year, and the EBSS that was received by all in 2022/23. In 2022/23, the £400 EBSS payment to electricity PPMs may have enabled the notable increase in the lower bound of electricity expenditure.

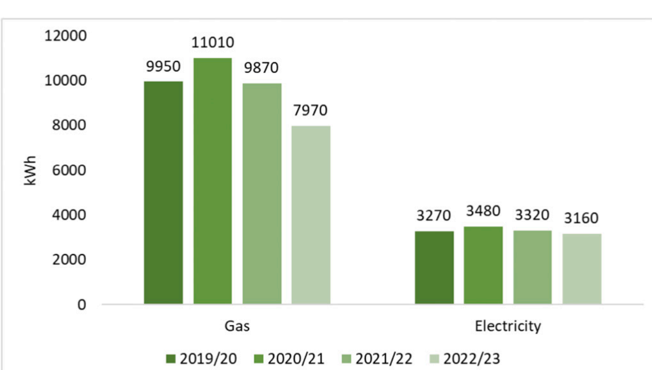

Fig. 4. Mean annual gas and electricity consumption per household
Sample sizes: vary from 7700 to 8500.

Table 6
National average household consumption figures for calendar years, Great Britain.

Year	Gas per household (kWh)	Electricity per household (kWh)
2019	11,901	3741
2020	11,753	3871
2021	12,374	3802
2022	10,050	3408

Source: [67].

Average annual energy expenditure rose from £1160 in 2019/20 to £2130 per customer in 2022/23. The latter figure includes the EBSS, so the household's own costs increased by 50 % to £1730.

Based on extensive analysis of the data for very low gas-using households [52], around 7 % of households with a gas connection have been found to be using electricity instead of gas for heating. These households scarcely use any (metered) energy for heating and are very likely the households facing the greatest hardship.

5.3. Self-disconnections

Each year more than half of households experienced self-disconnection from either gas or electricity or both (Fig. 7). The percentage of households experiencing disconnection decreased from 2019/20 to 2020/21, as explained earlier. Gas disconnections rose markedly in 2022/23. The notably higher percentage of gas disconnections as compared to electricity disconnections in 2022/3 is probably because of the £400 EBSS, credited to the electricity meter – which slightly reduced the number of households disconnecting from electricity.

Fig. 8 shows the distribution of hours of disconnection for gas and electricity combined, for households who self-disconnect, with each column representing 10 % of households. The distribution of hours of disconnection is very skewed, with a long tail of lengthy disconnection periods, so the median is used rather than the mean to illustrate typical values (Fig. 9). Some customers have very long periods of disconnection, these being greatest in 2022/23. For all households in all years (including those with no disconnections), 4.1 % have at least 240 h of disconnection per year, with at least four events of 12 h or more. This rose to 6.6 % of households in 2022/23.

As well as more customers having gas disconnections in 2022/23, they tended to last longer (Fig. 9). From 2019/20, gas disconnections were three to four times longer than electricity, rising to eight times longer in 2022/23.

Table 7 gives an overall picture of self-disconnections by household and dwelling type for all four years. On average, 63 % of all households self-disconnected in any year, and the households that self-disconnected did so five times each year for a total of 28 h. The likelihood of self-disconnection varies somewhat with characteristics of the dwelling and the household. The strongest correlation is between the age of the customer, with people under 25 much more likely – and people over 65 much less likely – to face self-disconnection. Younger households experience more and longer self-disconnections, especially if they live in less efficient homes with an EPC rating of F or G. Those living in smaller homes are slightly less likely to self-disconnect, but when they do, they tend to spend more time off-supply. Being on the Priority Service Register does not appear to protect customers from self-disconnection, as the rates of self-disconnection among those on PRS is similar to those not on PRS. Those receiving the Warm Home Discount disconnect for a slightly lesser time than the average.

F- and G-rated homes have more hours of self-disconnection, probably reflecting the higher cost of heating in those homes. Nearly all homes in Band A to C are C-rated (Table 1): EPC rating of C does not protect against high levels of self-disconnection.

Homes switching to electricity for heating are more likely to self-

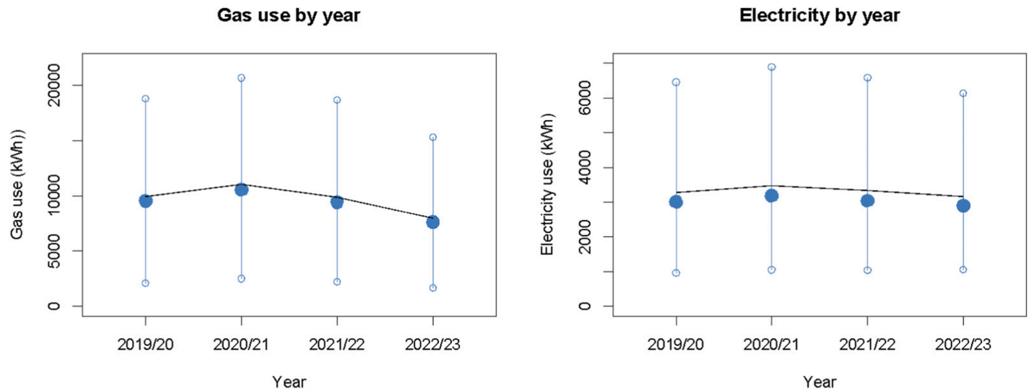

Fig. 5. Consumption of energy by year
Sample size: Varies by year between 7700 and 8500 households.

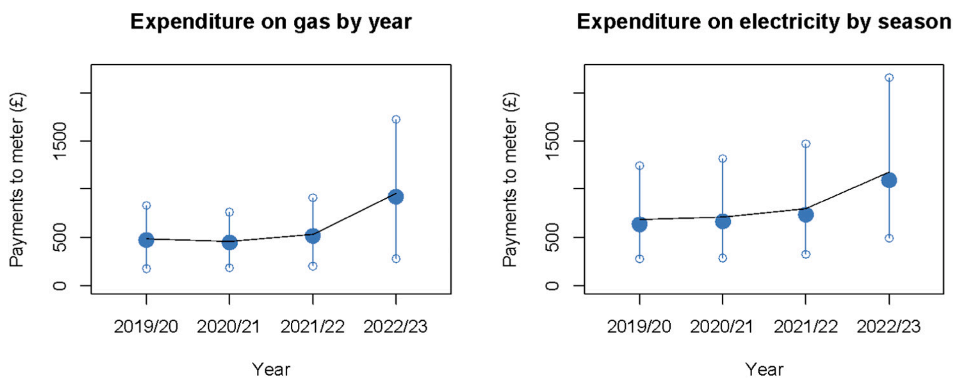

Fig. 6. Household expenditure on gas and electricity, by year
Sample size: Varies by year between 7700 and 8500 households.

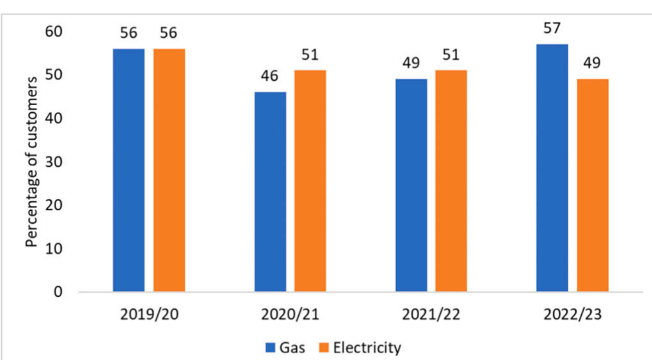

Fig. 7. Percentage of customers who experienced at least one self-disconnection during the year
Sample size: 32,700, from 10,100 households with data over 1 to 4 years.

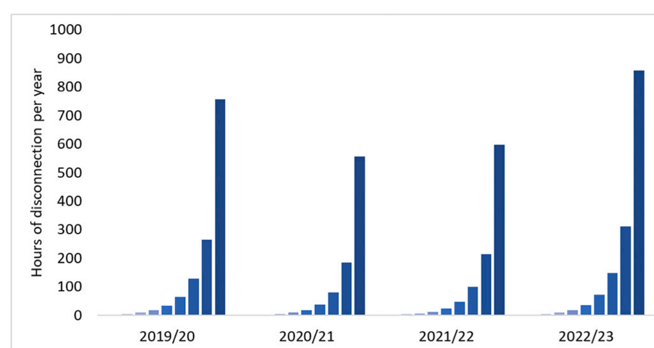

Fig. 8. Distribution of hours of disconnection by decile, gas plus electricity, for self-disconnecting households
Sample size: 20,500, from 7800 households.

disconnect for long periods: the most affected 25 % of households self-disconnect 10 times in the year for a total of 965 h per year (> 18 h per week). This is particularly concerning because electricity is important for safety and is the fuel of last resort.

5.4. Impact of cold weather

To look at the impact of cold weather and how it intersects with vulnerability, detailed analysis was carried out in three periods of cold weather in the North West, the region with most households represented in the sample. Using a single region enables use of detailed weather data. Results from the most severe period of cold are reported in full (analysis of two other cold periods are reported in [52]). Fig. 10 shows maximum, minimum and average temperatures before, during and after the cold period. Current Cold Weather Payments are linked to week-long periods of cold weather (Table 1), hence looking at 2 weeks rather than, say, 10 days.

Disconnections during the cold period are compared with 14 days before and 14 days after the cold weather event. Fig. 11 shows self-disconnecting households categorised into four groups: WHD, PSR, both and neither. The households most affected are those on PSR but not WHD. The eligibility criteria for these two programmes are completely different: WHD is for selected groups on means-tested benefits, whereas

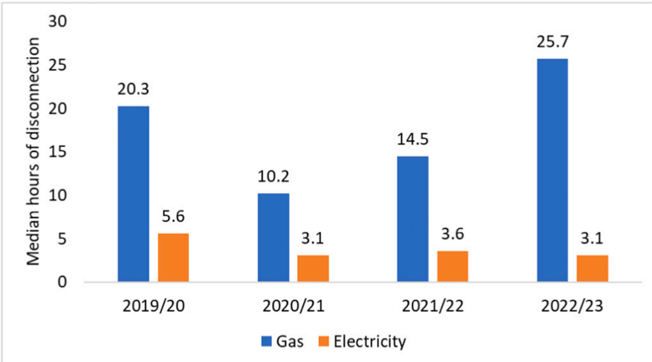

Fig. 9. Median hours of disconnections for self-disconnecting households, by year
Sample size: 20,500 cases from 7800 households.

Table 7
Proportion of different types of households and dwellings that were self-disconnected and the duration of the disconnection (yearly values averaged over the 4 years).

Customers	Self-disconnected (all customers, average per year over 4 years)	Median (interquartile range) total hours of disconnection over the year for those with disconnections*	Median (interquartile range) number of disconnections over the year for those with disconnections**
All	63 %	28 (5.3–164)	5 (2–17)
Age 18–25	78 %	51 (9.3–249)	8 (3–24)
Age 35–65	63 %	23 (4.7–141)	5 (2–16)
Age 65+	31 %	7.7 (2.3–42)	2 (1–5)
Size <70m^2	59 %	35 (6.2–225)	5 (2–16)
70-100 m^2	65 %	23 (4.8–129)	6 (2–22)
100 m2+	66 %	24 (4.8–128)	6 (2–17)
Priority service register	66 %	41 (6.0–55)	7 (2–23)
Warm homes discount	63 %	25 (4.5–134)	6 (2–20)
PSR, WHD and age 65+	30 %	6.9 (2.1–42)	2 (1–6)
EPC rating A-C	63 %	29 (5.3–175)	5 (2–17)
EPC rating D-E	63 %	27(5.4–152)	5 (2–17)
EPC rating F-G	68 %	37 (6.2–228)	6 (2–22)
Switching to electricity for heating***	63 %	63 (6.7–965)	3 (1–10)

* Gas hours plus electricity hours self-disconnected – when both are off it counts double, figures are average hours per year.
** When both electricity and gas are off it counts double, figures are average number per year.
*** Ignoring gas self-disconnections.

the PSR lists those deemed to be vulnerable to a loss of supply that is independent of their income.

Overall, more homes disconnected from the gas meter during cold periods, compared to before or afterwards, despite the greater need for heating. PSR homes were more strongly affected by self-disconnections during periods of very cold weather, even if they were on WHD.

Table 8 shows the mean minutes of self-disconnection from gas per household per day. Over 20 % of PSR homes self-disconnected during 7–21 December for an average of nearly an hour a day (Table 8). Given the temperatures, Cold Weather Payments would have been made to eligible households, but only after the event. This payment mechanism clearly does not enable people to stay warm in exceptionally cold periods.

6. Discussion

6.1. Sample representativeness

In interpreting these results, the question of representativeness is key. The sample was structured to be representative of Utilita's 720,000 smart PPM customers. As a result of choosing customers with EPCs, the sample is younger than Utilita's total customer base, but typical in other respects. There is no reason to think that Utilita's smart PPM customers are different from others in Great Britain in terms of household or housing characteristics, aside from their geographical distribution. However, as PPM customers have not been characterised as a population, uncertainty remains. Ofgem suggest: "around half of all PPM customers have smart meters, so we can be confident that trends applying to smart-PPM customers will apply to the whole prepayment customer base" [17]. While this may be true of trends, there should be caution around absolute values, given Utilita evidence that their traditional PPM customers had greater risk of self-disconnections and a drop of electricity consumption during winter 2022/23 of 21 % compared to the 3 % for smart PPMs [68].

This paper provides high quality, longitudinal data on a large, structured sample from an under-studied group of households. Because population-level data does not exist for either PPM customers or smart PPM customers, it is not possible to know exactly how representative this sample is.

6.2. Impact of increased prices on energy use and self-disconnections

Between 2019/20 and 2022/23, annual gas use fell by 20 %, while electricity use fell by 3 %. This is a significant decrease in the key heating fuel in households. Taken together, figures on energy use and self-disconnection demonstrate the considerable level of hardship and deprivation being suffered by many, and that fuel poverty has demonstrably worsened for the households in this sample. The change in gas use is considerably higher than for electricity, a pattern seen to a much lesser extent in data from samples with few PPM households [66].

The self-disconnection rates shown for this sample are about twice as high as those provided by Ofgem for smart PPMs. Given that Utilita is meeting Ofgem's requirement for friendly credit and has its own customer support measures, it is not likely that this is a company-related finding. Ofgem figures may be underestimating the true prevalence of self-disconnection, more research is needed to investigate these differences.

6.3. Supporting the fuel poor in winter 2023–24: Energy cost support scheme

In August 2023, based on the evidence underpinning this paper, a new policy – the Energy Cost Support Scheme – was proposed to replace the EBSS for winter 2023/24 [52]. Such a scheme could ensure that the fuel poor can afford the same amount of energy as before the 2022/23 price rises, by providing support equivalent to £1000 per household (the difference between average annual gas plus electricity costs in 2019/20 and 2022/23 (Fig. 6)).

The detailed proposal was that the following households should be provided with £1000 support for winter 2023/24:

- Eligible for the revised Warm Home Discount scheme (expected to be 2.8 million)
- With one or more prepayment meters (up to 4.5 million)
- Where electricity is the main metered fuel, but annual electricity consumption is below 4200 kWh (estimated 1 million)

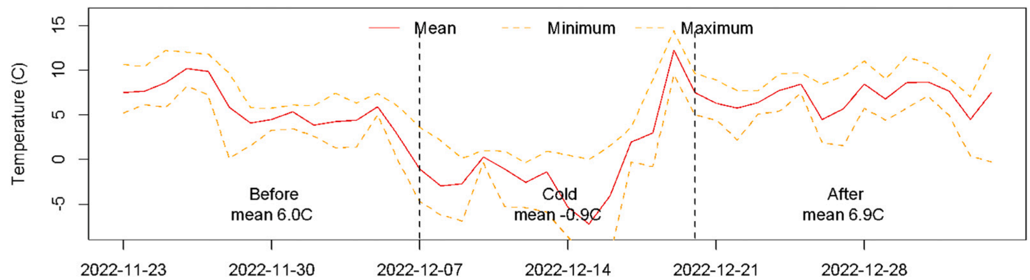

Fig. 10. Temperatures before, during and after a severe cold period from 7 to 21 December 2022.

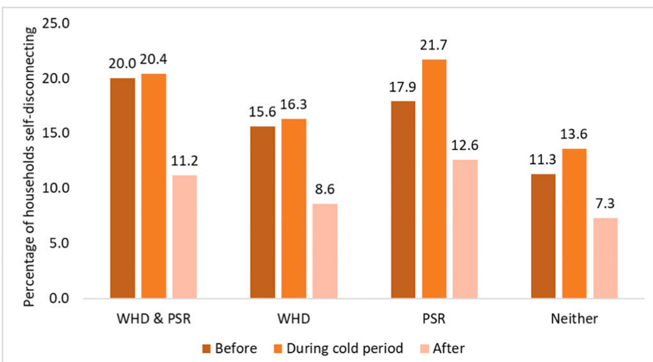

Fig. 11. Percentage of North West households self-disconnecting before, during and after 7–21 December 2022 by PSR and WHD
Sample size: WHD&PSR: 300; WHD: 290; PSR: 370; neither: 880.

Table 8
Gas self-disconnections, minutes per day, North West, by time-period and household category.

	Time period in relation to 7–21 December 2022		
Household category	Before	During	After
WHD	48.9	38.5	29.3
Non-WHD	36.3	36.7	32.5
PSR	56.1	53.0	44.0
Non-PSR	31.4	28.2	24.4

Sample size: 590 households on WHD, 1250 non-WHD, 670 households on PSR, 1170 non-PSR.

- Those who are extra-vulnerable to loss of energy supply for medical reasons and are on the Priority Services Register (estimated to be about 1 million).

The total could be over 9 million households, although there are probable overlaps between these groups.

The targeting criteria were based on information that energy companies already have, so that payment could begin by October 2023. Payment was proposed to be made directly onto the households' energy bills/ prepayment meters through reduced tariffs, by reverting to the unit rates in October 2020 (3.5p/kWh gas, 12.5p/kWh electricity). A reduced tariff is relatively easy for an energy supplier to implement. The policy design priority was to ensure that fuel poor households were not excluded from support, even if some households not at the risk of being in fuel poverty might benefit. It would have been affordable on the basis that the government had put aside £8 billion more to support energy users in the financial year 2022/23 than was needed for the Energy Price Guarantee [69]. £8 billion could be redirected to cover £1000 for 8 million households.

This proposal was submitted in evidence to the DESNZ select committee on 'Preparing for the winter' [70], presented to the parliamentary Committee on Fuel Poverty and adopted by the End Fuel Poverty Campaign, among other outreach activities in 2023. However, it was not adopted by the government.

6.4. Improving the cold weather payments policy

The evidence shows Cold Weather Payments are failing to protect vulnerable PPM households from self-disconnecting during cold weather. A replacement policy of 'Extreme Weather Payments' is proposed. Payments should be made in advance, not in retrospect of a cold weather event, so that the household knows they have secured extra money for heating. The trigger should be a prediction of minimum temperature of −4 °C or below, as this is equivalent to an average 24-h temperature of 0 °C, the current temperature threshold [71], using forecasts provided by the Met Office.

To determine what level of support would be needed, the Cambridge Housing Model v3.11 [72] was used to calculate additional heating needs and costs in extreme weather. This model, informed by data from 12,298 dwellings surveyed as part of the English Housing Survey, is used to carry out the calculations determining EPC ratings. It assumes living room average temperature of 19 °C, with other rooms heated to around 17 °C. Table 9 below shows energy use for heating, and costs, for an average day in January in winter (using 30-year average external temperature data, and nine English weather regions), compared to a single day at 0 °C. Focusing on the winter comparison, households with gas heating would incur additional costs of £3.41 a day, and those with off-peak Economy 7 storage heaters, additional costs of £6.49 a day.

The proposed Extreme Weather Payments are designed to protect households with either gas or electric heating – so for administrative simplicity, at least initially, the payment should be at least £6.50 for each day the average temperature is 0 °C or below. This means households using heating for gas will receive more money than needed. For those with smart PPMs, payments could be made to the meter, for other households, payments could be made to bank accounts, as at present (Table 1). If Extreme Weather Payments were made only to those currently eligible for Cold Weather Payments, many households identified as vulnerable to self-disconnection, e.g. many PSR households, would not receive this payment.

Table 9
Comparing heating costs – Average January or winter day and a day at 0 °C.

Chosen Period	Mean monthly energy for space heating in an average year (kWh)	Mean monthly energy for space heating in an average year at continuous 0 °C (kWh)	Additional energy per day (kWh)	Gas daily cost increase (10.1p/kWh)	Electricity daily cost increase (19.2p/kWh)
January	1664	2331	21.5	£2.17	£4.13
Winter	1283	2331	33.8	£3.41	£6.49

6.5. Other findings

The the current English definition of fuel poverty (LILEE definition) excludes all households in EPC bands A-C. However, 63 % of these households frequently self-disconnect from their energy supply (Table 7): therefore, a better definition is needed.

Smart meters and smart meter data can enable better delivery and targeting of support. This has been demonstrated with the EBSS payments and further uses of this infrastructure are proposed via new policies outlined in this paper. Experience during the Electricity System Operator's 'demand flexibility service' experiments [73], using benchmarking for individual customers, shows that smart meter data can be used in sophisticated ways to make payments to individuals based on their characteristics and patterns of energy use.

PSR households are one of the groups most likely to self-disconnect. This is the opposite of the aim of the register and indicates that this policy needs revision if it is to genuinely help vulnerable households.

7. Conclusions

Despite constituting about 15 % of UK households, PPM customers are poorly understood and under-researched. The introduction of smart PPMs offers new opportunities for understanding energy use by these households, their patterns of self-disconnection, the impact of policies supposed to relieve hardship and can inform better policy design. This paper has analysed smart PPM data to contribute to the limited literature on prepayment meter users.

Annual gas use fell by 20 % between 2019/20 and 2022/23, while electricity use fell by 3 %. This is a significant decrease in the key heating fuel, and a considerably larger drop than seen in better off, non-PPM households.

This research has found incidence of self-disconnection being nearly twice the previously reported prevalence. This is despite measures to reduce self-disconnection mandated by Ofgem and offered by the energy company and the government energy subsidies. In total, 63 % of the sample households self-disconnected at least once a year over these four years. The average household self-disconnected five times in a year, totalling 28 h of self-disconnection.

Groups of householders who use very little metered energy (gas plus electricity) or experience extremely high frequency and duration of self-disconnections have been identified. At 7 % of the sample, this is not a rare occurrence. More work is needed to find out why their energy consumption is so low, the effects of this under-consumption on their health and well-being, and what support they need.

The UK government made a substantial financial contribution to subsidise fossil fuel energy prices in winter 2022/23 – most of this money went to non-fuel poor households. Households on PPMs, who are disproportionally fuel poor, reduced their energy use and suffered additional self-disconnections from gas, their heating fuel. There is currently no reliable way to target energy-related payments to the fuel poor. If there were another fossil fuel price crisis, the government could only reliably help the fuel poor and vulnerable by helping everyone.

This paper proposed two key policies:

- A new support scheme –the 'Energy Cost Support Scheme' – to compensate the fuel poor for high energy prices from October 2023 – March 2024
- A revision to the Cold Weather Payment policy to provide better quality support during cold periods – renamed the 'Extreme Weather Payment'

This research has highlighted the advantages of paying money directly to smart PPMs and making payments promptly via energy retailers, rather than via social security systems. The ability of payments to be made within weeks of a decision to smart PPM customers could make smart PPMs a useful route to provide prompt financial support.

The literature shows that PPMs are generally popular with their users. Therefore, to enable people to keep benefiting from this payment option, it is important that more research focuses on understanding prepayment meter users' experiences, particularly when they are under extra pressure due to high prices and/or cold weather, and investigates innovative ways of using PPMs to deliver targeted and timely support to households.

CRediT authorship contribution statement

Tina Fawcett: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis. **Jason Palmer:** Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Nicola Terry:** Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation. **Brenda Boardman:** Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Uttara Narayan:** Writing – original draft, Investigation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Tina Fawcett, Jason Palmer, Brenda Boardman, Uttara Narayan, Nicola Terry reports financial support was provided by Utilita Giving. Tina Fawcett and Uttara Narayan report financial support was provided by UK Research and Innovation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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