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Public perceptions of demand side management and a smarter energy future

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Demand side management (DSM) is a key aspect of many future energy system scenarios^{1,2}. DSM refers to a range of technologies and interventions designed to create greater efficiency and flexibility on the demand side of the energy system³. Examples include the provision of more information to users to support efficient behaviour and new 'smart' technologies that can be automatically controlled. Key stated outcomes of implementing DSM are benefits for consumers, such as cost savings^{3,4} and greater control over energy use. Here, we use results from an online survey to examine public perceptions and acceptability of a range of current DSM possibilities in a representative sample of the British population (N = 2441). We show that, whilst cost is likely to be a significant reason for many people to uptake DSM measures, those concerned about energy costs are actually less likely to accept DSM. Notably, individuals concerned about climate change are more likely to be accepting. A significant proportion of people, particularly those concerned about affordability, indicated unwillingness or concerns about sharing energy data, a necessity for many forms of DSM. We conclude substantial public engagement and further policy development is required for widespread DSM implementation.

According to industry and government analyses, DSM has the potential to increase energy efficiency, and improve network flexibility^{3,4,5}. It could provide cost and operating benefits to energy companies, particularly in terms of automated meter readings and reduced customer inquiries, as well as benefits to society, for example through the reduction of carbon emissions^{3,5,6}. Currently, DSM is primarily discussed in relation to electricity (the focus here) and a key driver for deployment is the facilitation of integration of renewables onto electricity grids as part of efforts to reduce carbon emissions whilst also maintaining the reliability of supply. Increased proportions of renewables would increase reliance on electricity as opposed to gas, affect the

intermittency of supply, and generate greater need for flexibility on the demand-side of the energy system⁶. Given high levels of concern about climate change in the UK (and elsewhere)^{7,8}, it is perhaps surprising that there is not more of a focus on the environmental rationale for DSM^{4,9}. Consideration within the academic literature given to environmental framings indicate that whilst these are less popular than economic frames, they can actually be more impactful^{10,11,12}. Consumer benefits of DSM that are primarily highlighted center around the empowerment that increased control of electricity and information will provide, and particularly the potential for cost savings^{4,6}; this focus is perhaps partly due to the technological focus and prominent role of industry within debates. At present, it is unclear whether characteristics highlighted as benefits to consumers are perceived as such, and the implications for acceptance of DSM operations conjectured³.

A key technological intervention central for many DSM scenarios is the smart meter; these are energy meters (most commonly electricity) that in addition to measuring energy use also transmit information, thus facilitating a range of other technologies and systems^{3,9}. Rollouts of electricity smart meters have progressed in many places around the world with mixed responses, including opposition due to concerns over inaccuracies in data (e.g. Texas, US) and privacy (e.g. The Netherlands)^{13,14}. In the UK, rollouts are just starting and recent research indicates that most people are undecided in their support of smart meter installation¹⁵.

Beyond smart meters, research on public perceptions of DSM is limited, most being small-scale (given much of the technology is not currently widely available) and prone to recruitment bias given that those who take part in such trials are often particularly interested in technologies and/or the field of energy¹⁶. Evidence available indicates acceptance of DSM varies greatly depending on device and operation. Smart operation of

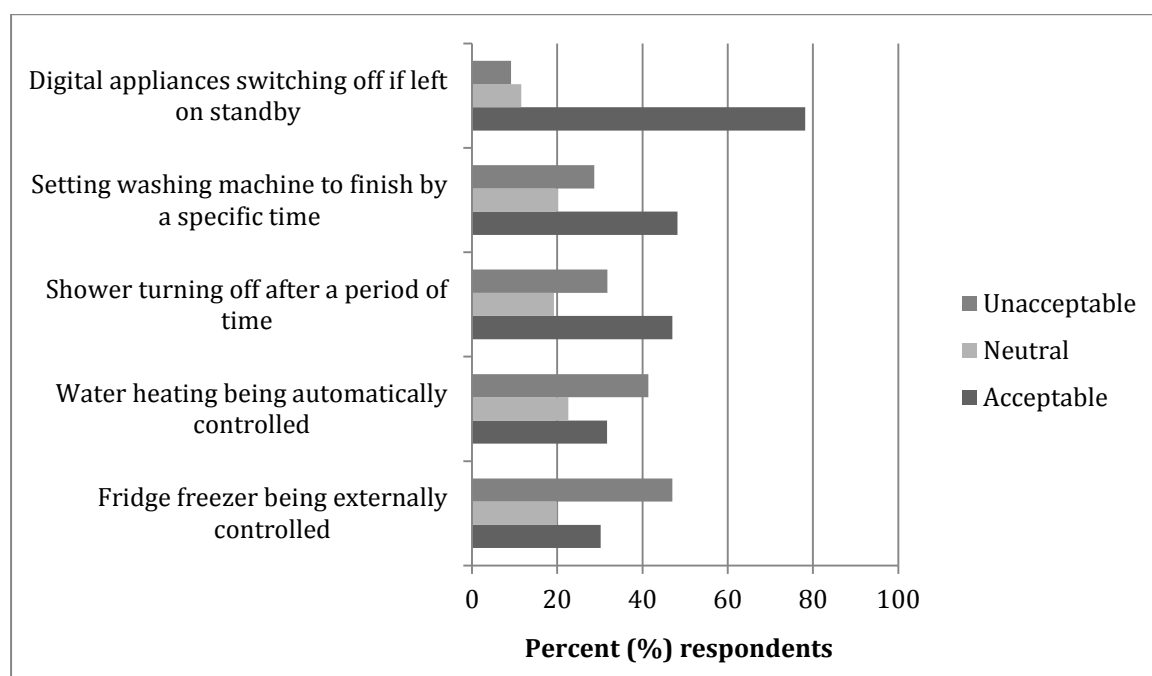
white goods (e.g. a delayed start to dishwasher use) is generally accepted and acceptance is higher if current living standards are perceived to increase¹¹ but is significantly lower for operation of in-home technologies like fridge-freezers and heating where there are concerns around comfort and health standards^{11, 17}. Privacy surrounding energy data has been much discussed within policy and academic discourse^{18,19,20}, however research is limited and mixed on whether public(s) are similarly concerned^{11,17}. There remains an urgent need to build an understanding of current public perceptions of DSM in order to inform the design and creation of DSM at a technical level so that such technologies are developed in the most useful and publicly desirable manner²¹.

Findings presented here arise from a survey of public perceptions of transformations to the UK energy system⁷. This online, UK representative, survey included questions examining perceptions relating to household energy use, acceptability of a range of DSM scenarios, and concerns about wider energy policy issues; see Method section for further details and Table 1 for specific question wordings and scale reliabilities.

Across our sample of UK residents (N = 2441), most participants (58%) indicated they were prepared to reduce current levels of personal energy use and were willing to spend more time thinking about electricity use (79%). There was a high level of interest in the electricity information that smart meters could make available ranging from 42% of participants who expressed interest in levels of electricity use by those in similar homes to 71% who indicated interest in which appliance uses most electricity. The majority of participants were willing to share this kind of data (ranging from 60% of participants willing to share with a government organisation to 73% with an energy regulator). However around a fifth of all participants were not willing to share electricity data with any groups specified.

Participants were asked how acceptable they considered five scenarios, designed to cover the broad range of DSM possibilities depicted within current energy policy visions^{3, 22}. Levels of acceptance varied across scenarios with the type of activity described, see Figure 1, however these variations were similar across individuals and formed a coherent scale ($\alpha = 0.75$), indicating commonality in the underlying drivers of acceptance.

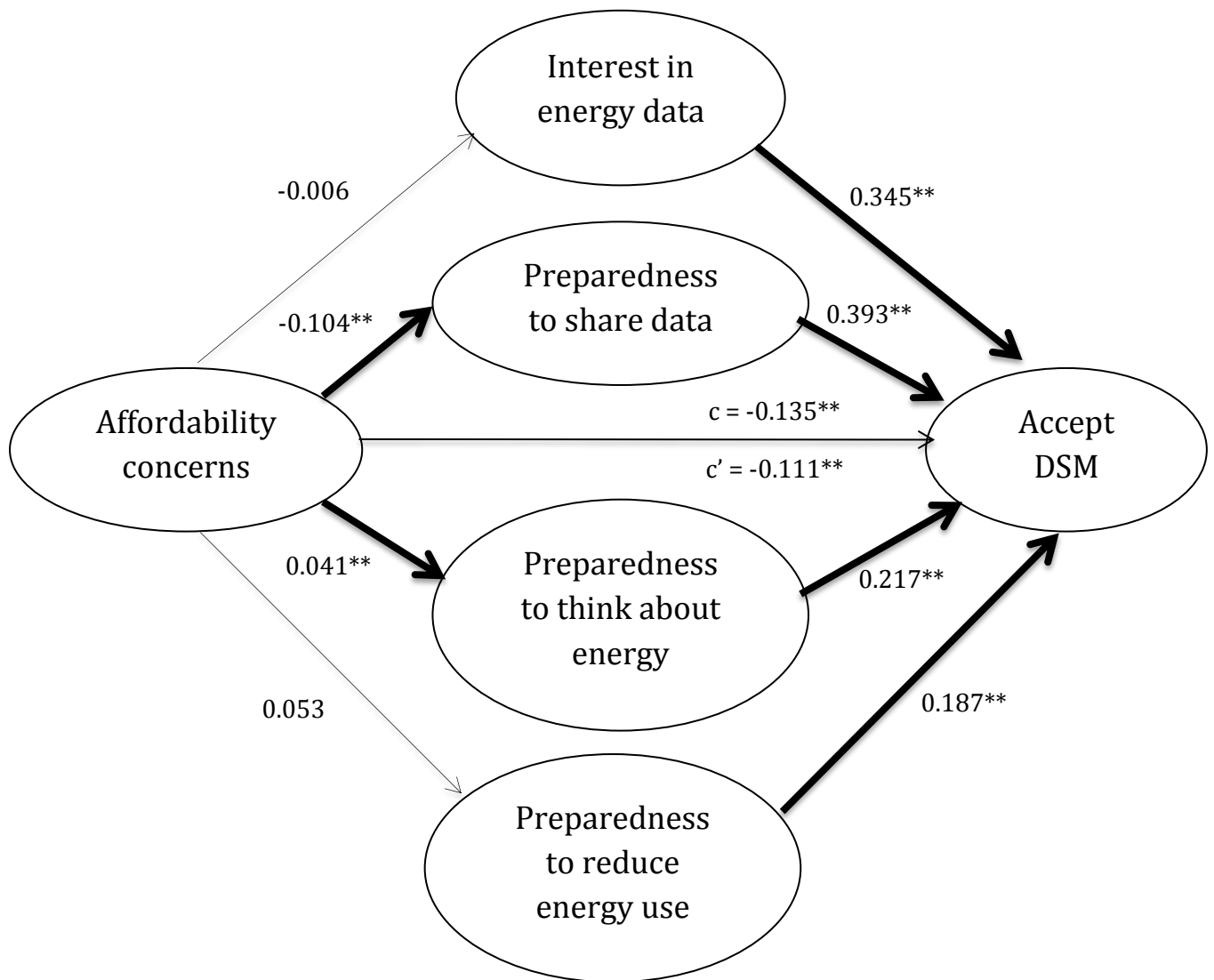
Figure 1 – Acceptability of DSM scenarios



In order to understand how acceptance of DSM relates to perceptions of household energy use, and wider energy policy issues, we modelled a stepwise linear regression; see Table 2 for correlations and regression models. Results showed that participants' level of interest in household electricity information, along with their preparedness to reduce energy use, to think about electricity use, and to share that information positively predicts acceptance of DSM. Broader concerns about energy security were unrelated to acceptance of DSM, however concerns about climate change were

positively related to acceptance. Perhaps most interestingly, a negative relationship between concerns about affordability of energy and acceptance of DSM is evident when basic perceptions about household energy management are included in the regression and thus controlled for (whilst direct correlations were non-significant); this indicates that perceptions about household energy use may reduce the otherwise negative relationship between affordability and acceptance of DSM.

Figure 2

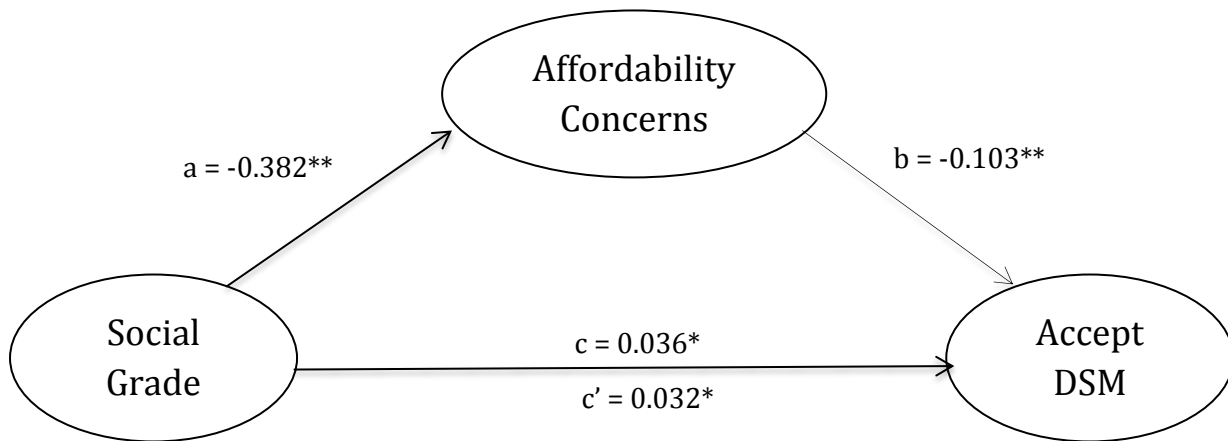


To consider the relationship between affordability concerns, perceptions about household energy management, and acceptance of DSM further we constructed a mediation model using ordinary least squares path analysis²³, see Figure 2. Concerns about affordability were related to a greater preparedness to spend time thinking about energy (0.041, $p < 0.05$), a lower preparedness to share energy data (-0.104, $p < 0.001$), and were unrelated to preparedness to reduce energy use (0.053, $p = ns$) and to interest in energy data (-0.006, $p = ns$). When the indirect effects of perceptions of household energy management were included in the model (direct effect = -0.111, $p < 0.001$; total effect = -0.135, $p = 0.001$) the negative relationship between affordability concerns and acceptance of DSM increased.

Given the key framing of DSM in terms of cost saving, the finding that affordability concerns were negatively related to acceptance of DSM was unexpected and thus we examined additional variables in our data that related to affordability concerns. We found that those who explicitly prioritised keeping energy prices affordable over energy security or climate change considerations were less accepting of the DSM possibilities outlined ($N = 592$, $M = 2.94$, $SD = 0.97$) than those who did not ($N = 1837$; $M = 3.38$, $SD = 0.97$; $t(2427) = 9.60$, $p < 0.001$). Acceptance of DSM was also significantly lower for people who owned a prepayment electricity meter ($N = 265$; $M = 3.10$, $SD = 1.02$) than those who did not ($N = 2164$; and $M = 3.29$, $SD = 0.98$; $t(2427) = 3.00$, $p < 0.01$).

Prepayment meters require payment in advance of electricity use and are more likely to be owned by those in fuel poverty²⁴. Furthermore less affluent social grades were associated with a lower acceptance of DSM and a further mediation model demonstrated that the indirect effect of greater affordability concerns amongst such social grades decreased further this already lower acceptance (direct effect = 0.032, $p < 0.01$; total effect = 0.036, $p < 0.01$), see Figure 3.

Figure 3



DSM has been positioned as providing cost savings for consumers^{4,5}, so the finding that affordability concerns and other cost concern proxies are actually related to a lower acceptance of DSM is important. Notably we highlight that our findings do not indicate that financial motivations to uptake DSM technologies are not important – previous research has demonstrated that many people are likely to be motivated by cost savings^{10,11}. Our data indicates that specifically those concerned about affordability (including those in lower social grades and those using prepayment meters) are less likely to uptake DSM technologies. Given that previous research indicates that people with prepayment meters may particularly benefit from engaging with energy displays²⁵ (and potentially other forms of DSM), it is particularly significant that this group are less likely to do so. Notably, respondents with affordability concerns were more prepared to think about energy and reduce their use but were less willing to share energy data. This fits with the idea that those with less power in society may perceive themselves as more vulnerable to exploitation²⁶.

Amongst individuals with affordability concerns it may, at least in part, be that potential financial benefits of DSM technologies are not apparent, or believed. Findings in the U.S. indicate scepticism over whether future smart technologies will reduce costs²⁷, concerns over payback periods, and hidden costs in energy technology investments¹¹. Indeed, we note that individuals in less affluent social grades and/or those who have energy affordability concerns are less likely to be able to invest in smart technologies due to lack of capital as well as lower levels of home ownership in this group²⁸.

Our results imply that those with affordability concerns might be more accepting of DSM possibilities that retain user control and autonomy. Future research should further explore individual differences alongside perceptions of other key dimensions of DSM, e.g. autonomy with regard to DSM technology operation, and whether behaviour changes are volunteered or enforced. Further advances in energy technologies and services may facilitate new systems of storing and manipulating energy data and it is important to consider issues of data sharing and trust as these are developed. Notably, across our sample, concerns about climate change were positively related to acceptance of DSM, in line with previous research^{10,11,12}, indicating that environmental reasons for deploying DSM should be considered when engaging members of the public.

The British public express a willingness to reduce their energy use and interest in spending time doing this, which has positive implications for DSM development. However our data also indicate that consumer perceptions of DSM benefits do not necessarily align with those highlighted in current policy and industry discourse. Successful DSM development should create new policy structures and incentives to reduce individual investment and risks associated with engaging with DSM. Steps taken should be consistent with broader energy policies (to engender trust), accompanied by clear communications, and should highlight a broader range of potential consumer and

societal benefits while also combating concerns (e.g. regarding financial risk, privacy etc.). In particular, whilst financial frames are more popular than environmental frames, these do not appear useful for everyone, particularly those concerned about costs, and it is notable that environmental frames, whilst less popular, are useful. We highlight that data here is specific to the UK public and that differing perceptions and priorities may be noted in other cultural and economic contexts (e.g. where questions of energy reliability are more salient). However, a drive towards renewables and DSM is evident in many countries indicating that these findings should be noted elsewhere and explored within local contexts.

Methods

The authors developed the survey instrument in conjunction with the social research company, Ipsos MORI. A full report of the survey data is available⁷. Ipsos MORI collected data using an online questionnaire between 2 and 12 August 2012. A nationally representative sample of Great Britain (that is England, Scotland and Wales) aged 18 years and older was recruited using quota sampling (N = 2441). Quotas for sampling were set according to socio-demographic variables including gender, geographic region, age, and employment status using data from the Labour Force Survey 2006 (the most recent data available which provides all of these variables). Participants were recruited topic blind (so that they were not aware that the survey focused on energy issues to help minimise response bias), using an email invitation directed at panellists within the Ipsos MORI Access Panel. The email contained information about the length of survey and incentive points awarded for participation. The survey took a median length of 48 minutes for respondents to complete.

The Ipsos Mori Access Panel consists of a pre-recruited group of individuals or households who have agreed to take part in online market and social research surveys.

Panellists are rewarded with points for every survey they complete and these can be redeemed for a variety of vouchers. Quotas were monitored on a daily basis and reminder emails were sent to panellists who had not completed the survey. The drop-out rate (22%) was in line with other surveys of this kind and evenly distributed across all sections of the survey. Data obtained were broadly representative of characteristics sampled and then weighted to be representative of these same characteristics for further analysis. Data was also collected on educational attainment and social grade. Social grade is a variable calculated based on occupation of the main earner in the household (previous occupation for those retired or unemployed) and classified according to ISCO (International Standard Classification of Occupations). Note that on average the sample had a slightly higher educational attainment than national data obtained from the 2011 UK census. We acknowledge that whilst participants were incentivised to participate, it is possible that those who continued to complete the whole survey may have a particular interest in energy issues and this is a possible bias in our sample; this is a common problem with national surveys focused on a particular topic.

Questions were carefully designed with input from a wider team of multidisciplinary academics, an expert advisory panel, and careful consultation of the existing literature using informed choice design principles²⁹. Given evidence that awareness of smart meters and DSM is low in the UK¹⁵, we provided participants with a short description of smart meters prior to asking questions regarding perceptions of electricity data. This stated that:

'As well as using less energy, we could become more flexible about when and how we use energy, for example in the home. Being more flexible in our energy use helps us reduce the likelihood of periods of extreme demand (when everyone uses a lot of energy at the same time this puts a strain on the overall electricity grid).

One way to be more flexible in our electricity use is through a new technology called smart meters. These new meters will be able to provide you with more detailed information about your energy use. Some of the information that will be available through a smart meter is listed on the next page.'

Additionally, preceding questions about DSM, participants were given some further information about the future of the energy system and why DSM might be needed.

There were told that:

'In the future, society might have to manage energy usage in other ways in order to prevent 'peaks' in energy demand (for example when everyone makes a cup of tea in an advert break during a popular TV show).'

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Author contributions

All authors contributed to the design of the survey utilised within the work presented. A.S., N.P and W.P. organised and managed the data collection. A.S. analysed the data. A.S. led in writing the paper, developing this with input from all authors.

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Author contributions

All authors contributed to the design of this study, and the discussion of results and implications. C.D. led the design of the survey instrument. A.S. analysed the presented data and led in writing the paper.

Figure Legends

Figure 1– Acceptability of DSM scenarios

Percent of survey respondents who indicated that each DSM scenario was acceptable, unacceptable, or who gave a neutral response. For full item wordings see Table 1.

Missing responses for each scenario varied from between 20-105 cases for each of the 5 scenarios giving final samples of between 2336 and 2421.

Figure 2 – Relationships between affordability concerns, perceptions about household energy use, and acceptance of DSM.

Energy security was included as a covariate in the model to ensure that we were considering concerns about affordability only. Due to missing data 257 cases were deleted listwise from the model leaving a sample of 2184. Coefficients are

unstandardized, * = $p < 0.05$, ** = $p < 0.01$; bold lines indicate significant relationships; c' represents the direct effect of affordability concerns on acceptance (holding other factors constant), c represents the total effect of affordability concerns on acceptance. Bias corrected bootstrap confidence intervals (CI) for indirect effects of preparedness to think about energy and preparedness to share energy data (0.0088 and 0.0407 respectively), based on 10,000 bootstrap samples, demonstrated that neither of these included zero (CI = 0.0013 to 0.0195 and 0.0630 to -0.0219 respectively).

Figure 3 – Mediation of the relationship between social grade and acceptance of DSM by affordability concerns.

Energy security was included as a covariate in the model to ensure that we were considering concerns about affordability only. Due to missing data 51 cases were deleted listwise from the model leaving a sample of 2390. Social Grade was coded so that higher values indicated higher levels of economic affluence. Coefficients are unstandardized, * = $p < 0.05$, ** = $p < 0.01$; bold lines indicate significant relationships; c' represents the direct effect of social grade on acceptance (holding other factors constant), c represents the total effect of social grade on acceptance. A bias corrected bootstrap CI for the indirect effect ($ab = 0.0039$) based on 10,000 bootstrap samples was entirely above zero (CI = 0.0013 to 0.0077).

Table 1 - Survey questions included in analysis

Construct	Question	Response Options
Climate change concerns	How concerned, if at all, are you about climate change, sometimes referred to as 'global warming'?	Four-point scale (not at all concerned–very concerned)
Energy security concerns ($\alpha = 0.76$)	How concerned, if at all, are you that in the next 10-20 years... ...there will be frequent power cuts? ...the UK will become too dependent on energy from other countries ...there will be a national petrol shortage? ...the UK will have no alternatives in place (e.g. renewables) if fossil fuels (gas, oil) are no longer available?	Four-point scale (not at all concerned–very concerned)
Affordability concerns ($\alpha = 0.69$)	How concerned, if at all, are you that in the next 10-20 years... ...electricity and gas will become unaffordable for you? ...petrol will become unaffordable for you?	Four-point scale (not at all concerned–very concerned)
Preparedness to reduce energy use	I am prepared to greatly reduce my energy use	Five-point scale (strongly disagree–strongly agree)

Prioritisation of energy priorities	Below are listed three key energy priorities for the UK government. Please rank them in terms of importance, where 1 = 'most important' and 3 = 'least important' (Most important responses provided here)	<ul style="list-style-type: none">- Keeping energy bills affordable for ordinary households- Making sure the UK has enough energy (preventing blackouts and fuel shortages)- Tackling climate change by using low-carbon energy sources
Pre-payment meter ownership	In which of the following ways do you currently pay for your electricity?	<ul style="list-style-type: none">- Direct debit- Quarterly payment on receipt of bill (payment on demand)- Pre payment meter (PPM, or card or key meter)
Time willing to spend thinking about electricity use	How much more time, if any, would you be willing to spend thinking about the electricity that your household uses?	<ul style="list-style-type: none">- A lot more time- A little more time- None at all

Interest in electricity information ($\alpha = 0.82$)	Please indicate whether you would be interested in obtaining any of this information about your own electricity use. Please select as many as you like.	<ul style="list-style-type: none"> - Which appliance is using the most electricity - Electricity usage by appliance - How much you are spending on electricity at a given time - Overall electricity use - Patterns of electricity use over a day, week, month, years - Electricity usage by room - Information about how much electricity is used on average by people in homes like yours
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Sharing electricity data ($\alpha = 0.86$)	How willing, if at all, would you be to allow the data recorded by your smart meter to be shared with the following? <ul style="list-style-type: none"> - Electricity supplier - Independent energy regulator - Independent third party for research 	<ul style="list-style-type: none"> - I would be willing for the data to be shared - I would be willing for the data to be shared but would have some concerns - I would not be willing for the data to be shared
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purposes

- Government organisation

<p>DSM acceptance ($\alpha = 0.75$)</p>	<p>Here are some examples of how energy usage could be managed differently. Please indicate your view towards the acceptability of each of the following situations using the sliding scale below.</p> <p>- Appliances such as digital boxes, TVs and computers automatically turning off if they are left on standby for a considerable amount of time</p> <p>- Your shower turning off after a set period of time each time your use it (e.g. 10 minutes). You would have to manually turn it on again if you wish to continue showering for longer.</p> <p>- Setting your washing machine to wash clothes before a certain time rather than right away. For example, you would turn on your washing machine and set a time by when the cycle has to be finished, e.g. 10am the next morning. The electricity network operator would then determine the best time to turn the washing machine on (e.g.</p>	<p>Five-point scale (unacceptable–acceptable)</p>
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by sending a signal to the appliance).

- Allowing your fridge or fridge-freezer to be switched off by your electricity network operator for short periods of time (provided the temperature of the fridge/freezer remains within a certain specified range).

- Rather than heating your water at the time of usage or at a pre-set time, you would indicate by which time you need to have hot water available. The electricity network operator would then determine the optimum time to run your boiler.

Note: α = Cronbach's alpha. This is a measure of scale reliability where scores higher than 0.7 are considered reliable.

Table 2 – Predicting DSM acceptance from perceptions about household energy use, and broader societal concerns

	r	B (SE)	t	B (SE)	t
Preparedness to reduce energy use	0.28**	0.16 (0.02)	7.49**	0.13 (0.02)	5.99**
Time willing to spend thinking about electricity	0.24**	0.22 (0.04)	5.33**	0.17 (0.04)	3.99**
Interest in energy information	0.24**	0.38 (0.06)	6.11**	0.35 (0.06)	5.63**
Willingness to share energy information	0.35**	0.39 (0.03)	12.73**	0.37 (0.03)	12.10**
Concern about climate change	0.26**			0.17 (0.03)	6.68**
Concern about energy security	0.05*			0.03 (0.04)	0.66
Affordability concerns	-0.02			-0.10 (0.03)	-2.92*
Adjusted R ²			0.19		0.21
F change			129.93**		15.82**

Note: * = $p < 0.05$, ** = $p < 0.01$. Variables were coded so that higher values indicated higher levels of that factor, e.g. higher values of concern indicate greater concern.

Collinearity tests yielded acceptable variance inflation factor (VIF) levels³⁰.