Empowering householders: Identifying predictors of intentions to use a home energy management system in the United Kingdom

Colin Whittle[a1], Christopher R. Jones[b2], Aidan While[c3]

[a]Department of Psychology, University of Cardiff, 70 Park Place, CF10 3AT, UK

[b]School of Psychology, University of Surrey, Guildford, GU2 7XH, UK

[c]Department of Urban Studies and Planning, the University of Sheffield, Winter St, Sheffield, S10 2TN, UK

[1]whittlec1@cardiff.ac.uk (corresponding author)

[2]c.r.jones@surrey.ac.uk

[3]a.h.while@sheffield.ac.uk

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Abstract

Trials of technologies designed to promote residential demand-side energy management (DSM) have found aggregate levels of load-shifting behaviour and curtailment in energy use. These aggregate data, however, mask considerable differences in people's engagement in DSM at an individual household level. We present the findings of a quantitative exploration of people's intentions to use a home energy management system (HEMS) for residential DSM in the United Kingdom. The technology acceptance model (TAM) was used in conjunction with constructs measuring psychological empowerment and environmental attitudes to explore participants' acceptance of a HEMS to facilitate load-shifting. Findings from a mediation analysis showed perceptions of the usefulness of the HEMS and its ease of use were important predictors of people's intentions to use one. They also highlight a potential conflict between an individual's home energy consumption goals and national DSM goals. The implications of these findings for understanding end-user acceptance of HEMS are discussed. We conclude that seeking opportunities to promote shared, internalised goals for residential DSM may be an avenue for increasing the uptake and use of technologies designed to enable load-shifting (and other energy conservation behaviours) among end-users.

Keywords

Goal internalisation; home energy management system; demand side management; smart energy technology; technology acceptance.

1 INTRODUCTION

Increasing demand for electricity (particularly at times of peak use) and an increasing reliance on intermittent, distributed renewable energy technologies, present key challenges for balancing supply and demand within electricity networks (Warren, 2014). Smart grids and associated information communication technologies (ICTs) are increasingly seen as providing a solution to these challenges by, for example, enabling residential demand-side management (Gungor et al., 2013). In the context of electricity consumption, demand-side management strategies include efforts to reduce overall electricity use (i.e. energy reduction) and to influence the times at which electricity is consumed (i.e. load shifting), such that demand more accurately matches the available supply (Warren, 2014). While previously only used in the industrial sector, the greater digital connectivity of smart grids is enabling demand-side management to be applied within the residential sector (Beaudin & Zareipour, 2015). Indeed, developing a smart energy system to enable flexible consumption, is a large component of the UK government's Clean Growth Strategy (HM Government, 2017) and Smart Systems and Flexibility Plan, which aims to "empower consumers and help people save up to £40bn off their energy bills in the coming decades" (pg. 4) through a combination of smart energy technology and time of use tariffs (Ofgem, 2017).

One form of digitally-connected 'smart' energy technology is the home energy management system (HEMS), which enables consumers to visualise, monitor and manage domestic gas and/or electricity consumption within their household (Kazmi et al., 2017; Van Dam, Bakker, & Buiter, 2013). In conjunction with advanced metering infrastructure (e.g. smart meters), a HEMS can also act as a gateway for consumers to access tailored information and services provided by smart grid operators, such as information on demand cycles (including points of critical use; Giordano & Fulli, 2012). This means a HEMS can act as an intermediary device between the network operators and the household and thus ostensibly empower householders to become more active participants in demand-side management by making them more aware of and responsive to their energy consumption (El-Hawary, 2014; Khan, Razzaq, Khan, & Khursheed, 2015; Sintov & Schultz, 2015).

Incentives to utilise a HEMS and participate in load shifting are often monetary, through the use of time-of-use tariffs, such as real-time (or dynamic) pricing (i.e. pricing that reflects the fluctuating cost of electricity production). The rationale behind real-time pricing is that increases to the unit cost of electricity consumption at peak times (relative to off-peak times), should encourage consumers to move their consumption habits towards off-peak (i.e. cheaper) periods. However, studies have found that householders can respond negatively to such initiatives for reasons that include scepticism over their ability to make cost savings (Spence, Demski, Butler, Parkhill, & Pidgeon, 2015) and the perceived inconvenience of changing their electricity consumption habits (Goulden, Bedwell, Rennick-Egglestone, Rodden, & Spence, 2014). Indeed, the success of smart energy technologies and real time pricing in motivating load-shifting has been mixed. On the one hand, trials have found reductions in peak demand at the aggregate level following the introduction of energy consumption feedback and real-time pricing tariffs. On the other hand, substantive individual differences in the amount of engagement and behaviour change were consistently found between the participating households, with some households time-shifting and reducing their energy consumption more than others (Bradley, Coke, & Leach, 2016; Gyamfi, Krumdieck, & Urmee, 2013; Le Ray, Larsen, & Pinson, 2018; Nilsson, Wester, Lazarevic, & Brandt, 2018; Srivastava, Van Passel, & Laes, 2018; Yan, Ozturk, Hu, & Song, 2018).

Understanding the factors that predict individuals' intention to engage with smart energy technologies will be important for maximising the uptake and utilisation of HEMS and their users' subsequent participation in DSM. With this in mind, the current study sought to identify predictors of people's intention to use a HEMS to participate in load shifting, using an extended version of the Technology Acceptance Model (TAM; Davis, 1989) as a basis for the investigation.

1.1 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) is used to predict people's intentions to use a given target technology, with the *intention to use* acting as a proxy for the individual's acceptance of the technology. According to the model, the two most proximal determinants of these use intentions are the individuals' beliefs about the *perceived usefulness* of the technology (i.e. the extent to which the performance of a task is perceived as being enhanced by the technology) and the *perceived ease of use* of the technology (i.e. the perceived degree of effort the use of the technology would require; Davis, 1989; Yousafzai, Foxall, & Pallister, 2007a). The TAM has been applied to a range of digital technologies, including communication and office systems (King & He, 2006; Lee, Kozar, & Larsen, 2003) and smart meters (Chen, Xu, & Arpan, 2017; C. K. Park, Kim, & Kim, 2012). Through these studies the TAM has proven to be a robust and parsimonious model of technology acceptance and use.

Perceived usefulness has frequently been identified as having a positive association with *intention to use*, as well as being a mediator of more distal predictors of intentions, such as subjective norms (Yousafzai et al., 2007a). Identifying the nature and influence of these external factors is seen as important to furthering understanding of technology acceptance, particularly as what determines a technology's *perceived usefulness* will vary from technology to technology (King & He, 2006). The relationship between *perceived ease of use* and *intentions to use* a given technology are less consistent in nature. Some studies have found a direct link between *perceived ease of use* and *intention to use*, whilst others find a mediated association via *perceived usefulness* (Yousafzai, Foxall, & Pallister, 2007b). In the present study, *perceived usefulness* was investigated both as a direct predictor of *intention to use* and as a mediator for *perceived ease of use* and each of the following variables now described.

Since its inception, the TAM has been augmented through the addition of further constructs (Yousafzai et al., 2007a). For example, Venkatesh and Davis (2000) identified that an individual's beliefs about the relevance of a new technology for completing their work-place goals helped to predict the *perceived usefulness* of the technology and people's intentions to use it. This factor was termed "job relevance", however, for the present study, this was amended to refer to *home relevance* and as such, referred to an individual's beliefs regarding the relevance of the HEMS to their home and their energy management goals.

Socially-relevant factors such as the *image* (or status) derived from using a given technology and the perceived *subjective norms* relating to its use have been identified as additional important predictors of technology acceptance (Moore & Benbasat, 1991; Yang, Moon, & Rowley, 2009). These more socially-relevant factors feature in an extension of the original TAM called the Technology Acceptance Model 2 (or TAM2), where they are included to explain people's perceptions of a technology's usefulness (Venkatesh & Davis, 2000). For example, perceived social (subjective) norms are conceptualised as being a person's expectations relating to the social acceptability of engaging (or not engaging) in a specified behaviour (Fishbein & Ajzen, 1975). The adoption and use of new technology is often argued to involve some consideration of how one's adoption of the technology will be viewed by significant others (e.g. friends, relatives, colleagues) and evidence for a direct effect of subjective norm on technology use intentions have been observed (Lorenz & Buhtz, 2017). Relatedly, with regards to *image* – the extent to which a technology is anticipated to enhance a person's social standing within their social groups – has been found to predict technology acceptance and use in some circumstances (Moore & Benbasat, 1991; Yang et al., 2009).

The perception of voluntariness has also been found to be important predictor of intentions. Voluntariness is conceptualised as an individuals' subjective perception of their freedom to use or avoid using a new technology (Moore & Benbasat, 1991; Tsai, Compeau, & Meister, 2017; Wu & Lederer, 2009). *Perceived voluntariness* has been investigated as a direct predictor of *intention to use* information technologies, with negative relationships typically hypothesised and found. This suggests that intentions towards digital technologies decrease with greater *perceived voluntariness* and increase when *perceived voluntariness* is low. This is to say that where technology use is perceived to be mandatory, people will be more likely to use it (i.e. comply) than when use is perceptively optional (e.g. Hardgrave, Davis, & Riemenschneider, 2003; Karahanna, Straub, & Chervany, 1999).

Based on the above literature, the social influence factors of *image, subjective norms* and *perceived voluntariness* were explored as predictors of perceived usefulness and intention to use, along with *perceived ease of use* and *home relevance.*

1.2 Pro-environmental worldviews and goal internalisation

The current study sought to model the importance of the established, abovementioned variables in shaping intentions to use a HEMS. In addition, we sought to model the importance of two additional variables: *pro-environmental worldviews* and *goal internalisation*.

To the extent that smart energy technologies, like HEMS, are promoted as 'green' technology options (Gangale, Mengolini, & Onyeji, 2013; Gelazanskas & Gamage, 2014; Hledik, 2009) one might anticipate that a householder's level of environmental concern should serve to shape their intentions to use them (Averdung & Wagenfuehrer, 2011; E.-S. Park, Hwang, Ko, & Kim, 2017). In line with this understanding, people's levels of environmental concern have often been linked to their propensity to engage in pro-environmental behaviours (Gifford & Nilsson, 2014) and has been found to distinguish the extent to which households engaged in demand-side management initiatives (Bradley et al., 2016). Furthermore, early adopters of smart energy technologies and self-selected participants of studies on the use of smart energy technologies, have often been identified as having pro-environmental values (Hargreaves, Nye, & Burgess, 2010; Van Dam et al., 2013; Woodruff, Hasbrouck, & Augustin, 2008).

The importance of environmental values in motivating environmental action is well-known and links to key psychological theories, such as Self-Determination Theory (SDT; Darner, 2009; De Groot & Steg, 2010; Steg & Vlek, 2009). SDT focuses on the extent to which a person's behaviours are either internalised and self-motivated or are more a product of the person responding to extrinsic factors (Ryan & Deci, 2000). At the highest level of internalisation, the goal to act in a particular manner (e.g. pro-environmentally) is integrated into the self and is pursued because the individual views the goal as either being intrinsically rewarding or as being of central value and importance to their sense of self (Ryan & Deci, 2000). Where the motivations for a behaviour are externally regulated or merely introjected, people are thought not to be responding to such an internalised desire to act but are instead responding on the presence of external demand (e.g. monetary reward or punishment) or are driven by ulterior motives (e.g. maintaining or bolstering one's sense of self-worth; De Groot & Steg, 2010; Ryan & Deci, 2000). External or introjected forms of motivation are limited as the motivation (and so goal pursuit) is likely to be extinguished if the reward or threat of punishment ends. In contrast, internalised goals are typically independent of reward or regulation and so will be pursued so long as the goal (and associated behaviour) is intrinsically rewarding or in keeping with the individuals' values (Geller, 2002; Ryan & Deci, 2000; Schultz, 2014; Steg & Vlek, 2009).

Of relevance to the current study, one should anticipate that the extent to which a person has or has not internalised the rationale for owning a HEMS might affect their acceptance of the technology. Specifically, utilisation of smart energy technologies, including HEMS, is currently being promoted in the UK as a means of fostering residential demand-side management (i.e. reduction in overall consumption and/or load-shifting behaviour). This is ostensibly to assist the UK government in meeting legally-binding, national targets for carbon-emissions reductions (HM Government, 2017). Such technologies are often promoted to end-users on individualistic, monetary-based grounds (which have been found to be ineffective for some and could undermine peoples' moral motivations to act; Bowles, 2008; Spence et al., 2015). However, for those who identify strongly with the general need to reduce energy consumption and carbon-emissions in the UK (an objective which could benefit society, as a collective), and have internalised this goal, one should anticipate there to be a positive impact upon the perceived usefulness of the HEMS.

Crucially, the internalisation of the national goal for a reduction in carbon emissions through demand-side management, could also lead people to place less importance on their own home energy management goals when considering the HEMS and their *intention to use* it (Leonard, Beauvais, & Scholl, 1999). That is, sharing in the national goal may mean that an individual householder will seek to transcend considerations of the direct relevance to their own home (i.e. *home relevance*) and instead consider the assistance that hosting the technology will have on the progression towards meeting the collectively beneficial, national goals (i.e. they utilise the technology for the 'greater good' despite there perceptively being nominal individual gain; Leonard et al., 1999; Shteynberg & Galinsky, 2011).

1.3 Theoretical conceptualisation and hypotheses

The current study sought to investigate the extent to which the TAM, augmented by the inclusion of measures of *subjective norm*, *image*, *perceived voluntariness*, *environmental worldview* and *goal internalisation*, would prove to be a good model of householders' intentions to use a HEMS. *Intention to use* a HEMS was investigated through the use of information choice questionnaires (ICQs) and focussed upon using a HEMS for the purposes of demand-side management, particularly load shifting.

A total of 9 hypotheses were investigated. The hypothesised relationships are summarised in Figure 1. On the basis of extant research into the TAM, *perceived usefulness* was investigated as a predictor of intention to use, as well as a mediator of the relationships between *intention to use* the HEMS and the other factors of interest. The following predictions were made about the anticipated core relationships within the model:

H1a: *Perceived usefulness would positively predict intention to use a HEMS; and*

H1b: *Perceived ease of use would positively predict intention to use a HEMS, via perceived usefulness.*

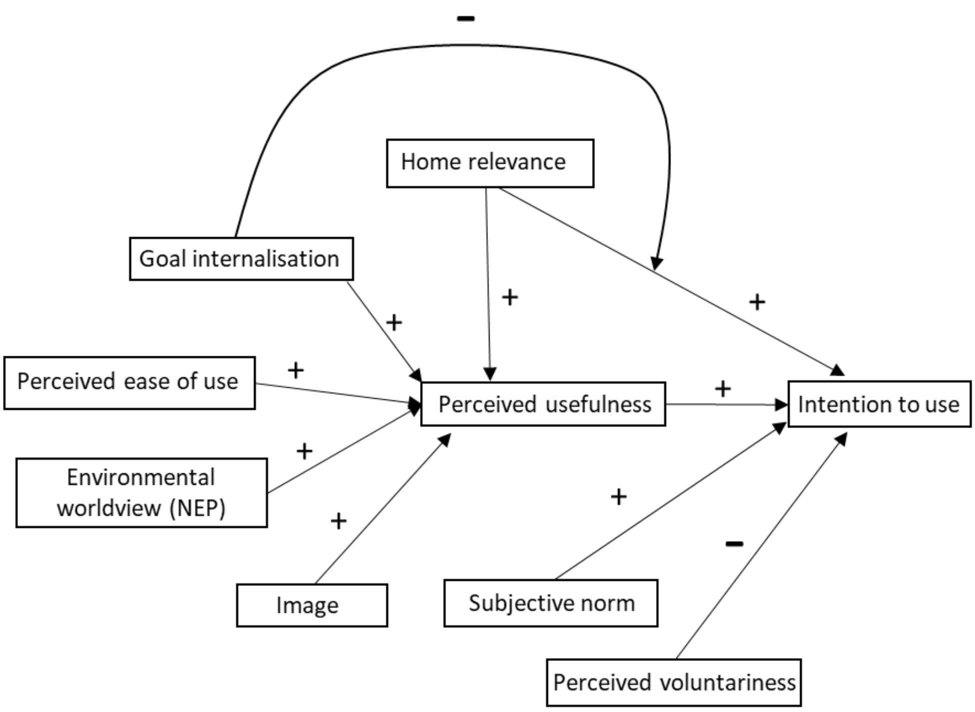

Figure 1. Conceptual diagram of the hypothesised predictors of Intention to Use a Home Energy Management System (HEMS). + signifies a positive association; – signifies a negative association.

In recognition of the advances in the identification of key 'external' factors within the TAM2, the following predictions were also made relating to perceptions of *home relevance, voluntariness, image and subjective norms*.[1] First, the perceived compatibility between the HEMS and household energy-use goals (i.e. *home relevance*) was anticipated to positively affect people's intentions to use the technology, via perceptions of perceived usefulness.

H2: *Home Relevance would positively predict intention to use the HEMS, via perceived usefulness.*

Perceived voluntariness of using a HEMS was anticipated to have a direct *negative* association with people's intentions to use the technology. To the extent that adoption and use of a technology is deemed to be mandatory (i.e. involuntary) one would expect broad (if reluctant) acceptance and use of that technology. Being that the use of a HEMS is currently voluntary, however, we anticipated a negative relationship between *perceived voluntariness* and *intentions to use* the technology.

H3: *Perceived voluntariness will negatively predict intention to use a HEMS.*

To the extent that adoption of a HEMS is viewed as a socially desirable act – by outwardly signalling a householder's willingness to act to change their residential energy-use behaviour (e.g. Griskevicius, Tybur, & Van den Bergh, 2010) – we predicted that the any *image* (i.e. status) benefit inferred by the adoption of the technology would exert a positive effect on people's *intentions to use* the technology. We also anticipated that because of the framing of HEMS as a device for participating in neighbourhood-level load-shifting, that *subjective norms* relating to HEMS usage would share a positive relationship with use intentions.

[1] Other 'external' factors have been explored within the TAM2 including, result demonstrability and output quality. In the current study these constructs are not considered on the grounds that people would yet to have experience with or be able to comment authoritatively upon the output quality of the target technology in a load shifting context.

H4*: Perceived image (or status) benefits from using a HEMS would positively predict intentions to use the technology, via by perceived usefulness.*

H5*: Subjective norms will positively predict intention to use a HEMS.*

We also sought to extend the theoretical basis of the TAM2 by incorporating measures of *environmental worldviews* (as assessed by the New Ecological Paradigm [NEP] scale, Dunlap et al., 2000) and *goal internalisation* (i.e. the extent to which people identified with the national need to reduce energy consumption in the UK). On the grounds that HEMS would be presented as a 'green' technology, we anticipated that pro-environmental worldviews should share a positive relationship with people's *intentions to use* the technology (via *perceived usefulness*) and that *goal internalisation* should (1) positively predict use intentions (via *perceived usefulness*) and (2) negatively moderate the relationship between *home relevance* and *intention to use*.

H6*: Stronger pro-environmental worldviews will positively predict intention to use a HEMS, via perceived usefulness.*

H7a*: Goal internalisation will positively predict intentions to use a HEMS, via perceived usefulness.*

H7b*: Goal internalisation will negatively moderate the relationship between perceived home relevance and intention to use a HEMS.*

2 METHODS

2.1 Design and participants

Given that HEMS are an emerging technology, it was deemed unlikely that participants would have had direct experience of using one and/or be familiar with the rationale for their development. As such, an online Information and Choice Questionnaire (ICQ) method was employed for this research (de Best-Waldhober et al., 2009; ter Mors et al., 2013). ICQs have been shown to foster opinions which are more confident, stable, and consistent over time than regular questionnaire-based surveys, particularly when dealing with unfamiliar topics (Van Der Salm, Van Knippenberg, & Daamen, 1997).

The questionnaire, advertised as a "Survey on Household Energy Use", was hosted by Qualtrics (an online survey platform provider). The study was advertised via staff emailing lists at four UK universities (comprising a mix of academic and non-academic staff) and via social media posts on Twitter and Facebook. Participants had to be aged over 18 years and living in the UK. They were self-selected, in that, those who wished to participate in the study followed a link provided in the advert to the Qualtrics website and the ICQ. They accessed and completed the ICQ on their own electronic devices and in their own time. A collection period of one week was allowed. Of the 108 participants who completed the ICQ, 1 case was removed for missing more than 50% of item responses. Of the 107 remaining cases, 7 (6.54%) had missing data (totalling 11 data points). Multiple imputation was used to estimate and replace the missing values (Donders, Van Der Heijden, Stijnen, & Moons, 2006).

The modal participant was aged between 38 and 41 years old (14.95%), held a doctoral degree, and lived in a semi-detached property that they owned (see Appendix B). One sample *t*-tests versus relevant scale midpoints revealed that, on average, participants shared the collective UK energy-management goal (indicative of collective *goal internalisation*) (M = 4.17 SD = 1.04, $t(106) = 6.68$, $p < .01$) and held strong pro-environmental worldviews (M = 3.75 SD = .06, $t(106) = 12.31$, $p < .001$).

2.2 Materials

2.2.1 Generating and validating the contextual information for the ICQ

Academic publications on smart grids (e.g. Naus, Spaargaren, van Vliet, & van der Horst, 2014), load shifting (e.g. Gottwalt, Ketter, Block, Collins, & Weinhardt, 2011), neighbourhood energy feedback (e.g. Ilic, Da Silva, Karnouskos, & Griesemer, 2012) and HEMS (e.g. Beaudin & Zareipour, 2015; Khomami & Javidi, 2013; Van Dam et al., 2013) were used to create the contextual information for the ICQ (see the supplementary materials for the information provided to participants).

The narrative created to contextualise the survey for participants provided an explanation of the current methods of estimating electricity consumption in the UK and the challenge of peak electricity demand (the full information is available in Appendix A). The need to reduce the peaks in electricity demand by changing when people (in this case the participant) use electricity was emphasised. The need for network operators to be able to better monitor electricity consumption in order to more accurately meet demand was also mentioned. Real-time pricing was then detailed, before HEMS were introduced as a possible solution to tackling peak demand. HEMS were described as a technology that could encourage shifts in when people would use electricity by displaying their real-time energy use and the current monetary cost. The opportunity to save money through consuming during off-peak times was emphasised.

2.2.2 Validating and Piloting the ICQ

To ensure the accuracy of the contextual information that would be provided to participants in the study, 23 individuals with expertise in smart-grid technologies (identified via an internet search) were contacted and consulted (April-June 2014). Twelve experts responded to the request for assistance. Where appropriate, feedback on accuracy and clarity of the contextual information from these experts (collected via online survey) was used to amend the information.

The full questionnaire was piloted on a small sample of participants (5 males, 7 females; Age range: 18-58 years) recruited via opportunity sampling (survey items available in

Appendix C). All participants reported that they had understood the contextual information provided to them and were able to competently answer the subsequent questions.

2.2.3 Measures

In line with Venkatesh and Davis (2000), all scale items, except those for *environmental worldview* and *goal internalisation*, used a 7-point Likert response scale (1 = strongly disagree; 7 = strongly agree). Following Dunlap, Liere, Mertig, and Jones (2000), *environmental worldview* items used a 5-point Likert scale and, in line with Menon (1999), *goal internalisation* used a 6-point Likert scale. All the items used to measure the investigated factors are available in Appendix C.

2.2.3.1 Intention to use a HEMS

Intention to use a HEMS constituted the main dependent variable. Participants' intention to use a HEMS was measured using two self-reported items (adapted from Fishbein and Ajzen (1975): (1) *"Assuming I have access to the HEMS, I intend to use it"*; and (2) "*If I had access to the HEMS, I predict that I would use it".* The internal consistency of the items was excellent (α = .94), so the item scores were averaged to yield an overall measure of *intention to use*.

2.2.3.2 Perceived Usefulness, Ease of Use and Home Relevance

All items were adapted from those used by Venkatesh and Davis (2000). The wording of some items had to be adapted to fit to context of the research, which focused on the home rather than the workplace. For example, one of the items for assessing *perceived usefulness* (6 items, α = .97) was altered from *"Using the system in my job increases my productivity"* to *"Using the HEMS in my home would increase my ability to control my energy use".* The *perceived ease of use items* (6 items, α = .93) were similarly adapted. Venkatesh and Davis's (2000) measure of job relevance was converted to one of *home relevance* (2 items, α = .93) (e.g. *"In my home, usage of the HEMS would be important"*). Items pertaining to each of the respective individual factors were averaged to form composite scores of (a) *perceived usefulness,* (b) *perceived ease of use*, and (c) *home relevance*.

2.2.3.3 Perceived Voluntariness, Image and Subjective Norms

The items to measure *perceived voluntariness* (3 items, α = .66), *image* (3 items, α = .87) and *subjective norms* (2 items, α = .86) were also adapted from Venkatesh and Davis (2000) such that each item related to perceptions of HEMS. Item scores for their respective factors were averaged to form a composite score for each factor (Kline, 2013).

2.2.3.4 Environmental worldview

Participants' *environmental worldview* was assessed using the revised 15-item New Ecological Paradigm (NEP) scale (Dunlap et al., 2000). Items consist of statements relating to the human-nature relationship (e.g. *"Humans are severely abusing the environment"*). The 7 negatively-worded items (which assess the Dominant Social Paradigm) were reverse coded for analysis, such that higher scores on each item equated to a stronger *environmental worldview*. The internal consistency of the scale items was satisfactory (α = .84) and so item scores were averaged to generate a single composite measure of *environmental worldview*.

2.2.3.5 Goal internalisation

Goal internalisation was measured using items adapted from Menon's (1999) measure of psychological empowerment. Three items were adapted to capture participants' internalisation of UK governments' goal of energy reduction by 2030, particularly focusing on intrinsic motivation ("*I am inspired by the energy reduction we are trying to achieve in the UK"; "I am inspired by the energy reduction goals of the UK"; and "I am enthusiastic about working towards lower energy usage in the UK")*. Items scores were averaged (α = .72) to form a composite measure of *goal internalisation*.

3 RESULTS

3.1 Overall perception of HEMS

On average, participants indicated an intention to use a HEMS. Participants perceived HEMS as useful, easy for them to use and relevant to their home. They also perceived the use of a HEMS as being voluntary. Participants tended to disagree that a HEMS would provide them with an increased social status (*image*) and were unsure about whether people important to them would wish them to use a HEMS (*subjective norm*). One sample *t*-tests confirmed that the means for each of these constructs did deviate significantly from the scale mid-point (see Table 1).

Table 1. Mean scores and significance tests for deviation from the midpoint for TAM2 responses to the HEMS.

Subscale	Mean (*SD*)	*t*	*p*
Intention to Use	5.51 (1.58)	9.90	<.001
PU	5.27 (1.46)	8.95	<.001
PEOU	5.08 (1.16)	9.65	<.001
Voluntariness	4.67 (1.22)	5.65	<.001
Image	2.74 (1.31)	-9.98	<.001
Home Relevance	4.75 (1.69)	4.61	<.001
Subjective Norm	4.00 (1.39)	0.00	1.0

Significance values based on 10,000 bootstrapped sample. Scale Midpoint of TAM2 =4; $N = 107$; $df = 106$

3.2 Predicting Perceived Usefulness (PU) and Intentions to Use a HEMS

To test the principal hypotheses, a simple mediation analysis (using ordinary least squares path analysis) was conducted. As shown in Table 2 and illustrated in Figure 2, p*erceived usefulness* had a significant, positive relationship with *intention to use* (confirming Hypothesis 1a). *Perceived ease of use* also shared a positive, indirect relationship with *intention to use*, via *perceived usefulness* (confirming Hypothesis 1b, see Table 3).

Table 2. Standardised coefficients from mediated model.

	Perceived usefulness	**Intention to use**	**Total effect**
Perceived usefulness	-	**.65*** **	-
Perceived ease of use	**.26*** **	-.02	**.15***
Perceived voluntariness	.01	-.02	-.02
Image	.11	-.09	-.02
Home relevance	**.51*** **	**.33** **	**.66*** **
Subjective norm	-.10	-.03	-.09
Goal internalisation	**.30*** **	.07	**.25** **
Environmental worldview	**.12***	-.01	.07
Constant	<.01	<.01	<.01
	R^2 = .77,	R^2 = .83,	R^2 = .73,
	$F(7, 99)$ = 46.21	$F(8, 98)$ = 60.58	$F(7, 99)$ = 38.56
	p < .001	p < .001	p < .001

*p< .05, **p <.01, ***p<.001. P values < α = .05 are emboldened. Standard error estimated from a bias-corrected bootstrap sample of 10,000. Model estimated with model 4 in the statistical software, PROCESS (Hayes, 2017).

Table 3. Estimates of the indirect effects of hypothesised factors on *Intention to Use* as mediated by *Perceived Usefulness*.

Predictor	Std. Coeff. (β)	SE	Lower level CI	Upper level CI
PEOU	.17	.06	**.08**	**.31**
Image	.07	.04	**.01**	**.16**
Home relevance	.33	.10	**.17**	**.54**
Goal internalisation	.18	.08	**.05**	**.38**
Environmental worldview	.08	.05	**.01**	**.20**

Confidence intervals (CI) and Standard Error (SE) estimated from a bias-corrected bootstrap sample of 10,000. Confidence intervals above zero are emboldened.

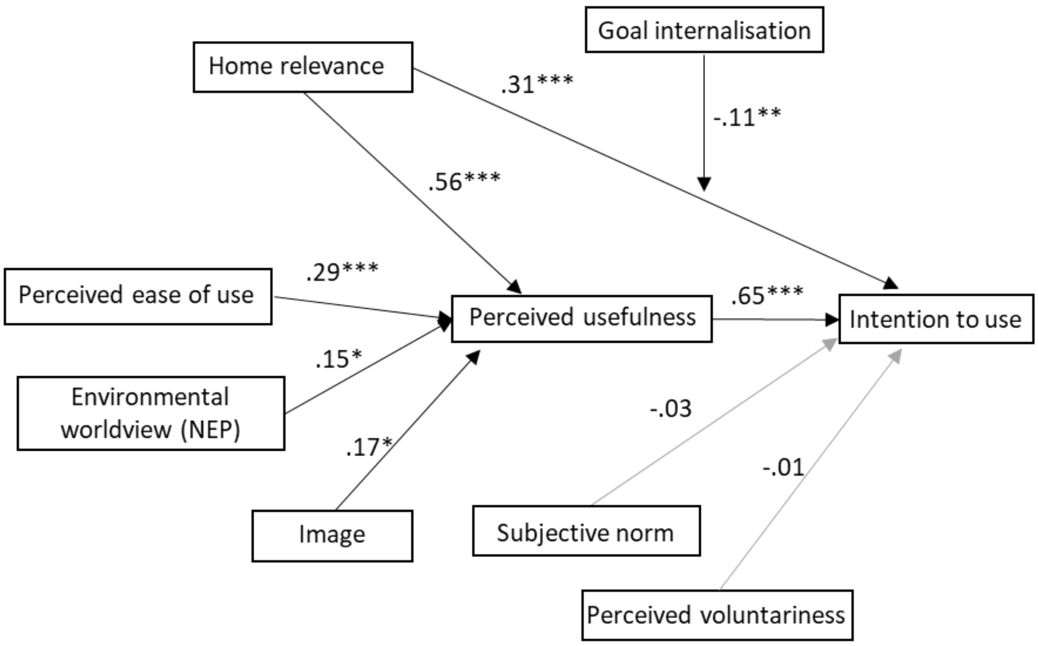

Figure 2. Predicting *Intention to Use* a home energy management system (HEMS) with *Goal Internalisation* and *Home Relevance* interaction. **p*< .05, ***p* <.01, ****p*<.001. Grey lines indicate statistically non-significant associations (p > .05).

Home relevance, *environmental worldview*, and *goal internalisation* had the hypothesised positive, indirect relationships with *intention to use* via *perceived usefulness* (confirming Hypotheses 2, 6 & 7a, see Table 3). However, there were two unexpected findings. The first was that *image* had a significant, indirect relationship with *intention to use*, despite not having a statistically significant relationship with *perceived usefulness* (only partially confirming Hypothesis 4, see Table 3). The second was that *home relevance* maintained a significant, direct relationship with *intention to use*, independent of *perceived usefulness.* Two further findings contradicted expectations, with neither *perceived voluntariness* nor *subjective norms* having a significant relationship with *intention to use* (hypotheses 3 and 5 were not supported).

To explore the interaction between *home relevance* and g*oal internalisation* (Hypothesis 7b), the interaction term for *home relevance* and *goal internalisation* was added to the mediation model for *intention to use*. The model for *perceived usefulness* was significant (R^2 = .73, $F(6, 100) = 45.14$ $p < .001$), as was the model for *intention to use* (R^2 = .85, $F(9, 97) = 58.80$ $p < .001$). Estimates for the moderated model are shown in Figure 2 (full model estimates can be found in Appendix D). In the moderated model, the coefficient for *image* moderately increased and became statistically significant ($\beta = .17$ $p = .01$). As the variance inflation factors (VIF), tolerances and proportion of variance did not suggest multicollinearity (Bowerman & O'connell, 1990; Menard, 2002), both *goal internalisation* and *image* were retained in the mediation model and the implications of estimates in both models are discussed.

The interaction term was statistically significant ($\beta = -.11$ $p <.01$). In line with the pick-a-point approach (Aiken, West, & Reno, 1991), the relationship of *home relevance* with *intention to use* was explored for participants' whose *goal internalisation* values were lower than average or higher than average (-1 or +1 standard deviations of the mean *goal internalisation* value, respectively). The conditional, direct effect of *home relevance* on *intention to use* at these lower and higher values of *goal internalisation* are shown in Table 4. The negative interaction between *home relevance* and *goal internalisation* indicated that the more that participants subscribed to a national goal of conserving energy, the weaker the association between the personal (i.e. home) relevance of a HEMs and their intentions to use the technology (confirming Hypothesis 7b).

Table 4. The standardised, conditional direct effect of *Home Relevance* on *Intention to Use* at less (-1) and greater (+1) values of *Goal Internalisation* [a].

Goal internalisation (*SD*)	β	SE	*P*	Lower level CI	Upper level CI
-1.00	.42	.08	<.001	.27	.57
.00	.32	.07	<.001	.18	.45
1.00	.21	.08	.01	-.05	.37

Confidence intervals (CI) and Standard Error (SE) estimated from a bias-corrected bootstrap sample of 10,000.
[a] As the variables have been standardised, the mean value of the goal internalisation is 0.
β = standardised coefficient.

4 DISCUSSION

Householder acceptance of sustainable energy technologies will be important for the realisation of future, residential electricity demand-side management initiatives (Geelen, Reinders, & Keyson, 2013; Goulden et al., 2014). However, whilst effective at the aggregate level, trials show large variations in the level of engagement by individual households (e.g. Srivastava et al., 2018). The present study explored key factors likely to be associated with peoples' intentions to use a Home Energy Management System (HEMS) for load shifting.

The findings indicate that overall perceptions of the HEMS in our study were positive. Participants viewed a HEMS to be a useful means of shifting their household energy consumption and indicated a favourable intention towards using one in their home. The findings add support to the technology acceptance model (TAM) as a model of intentions to accept household technological innovations (c.f. King & He, 2006; Schepers & Wetzels, 2007; Yousafzai et al., 2007b). They also confirm the mediating role of *perceived usefulness* in shaping people's *intentions to use* a given energy technology (Venkatesh & Davis, 2000). The findings also support the TAM literature that suggests that the relationship between *perceived ease of use* and *intention to use* is fully mediated by *perceived usefulness* (Yousafzai et al., 2007b).

Alongside *perceived usefulness* and *perceived ease of use*, we also investigated the relevance of a series of further factors – informed by research into the TAM and TAM2 – anticipated to shape people's *intention to use* a HEMS. The findings indicate that perceptions of *home relevance,* having stronger *environmental worldview* and sharing the collective goal of reducing the UK's energy consumption (*goal internalisation*) are all related to increased *perceived usefulness* of a HEMS and, in turn, *intentions to use* one. The retention of these variables within the model makes sense, to the extent that HEMS are framed (and were in this experimental context) as a household technology with the potential to yield environmental benefit through the promotion of changes in domestic energy consumption practices.

By contrast, perceptions of what important others' think about HEMS usage (*subjective norms*) and the extent to which the use of a HEMS is perceived as voluntary (*perceived voluntariness*) were neither related to *perceived usefulness* nor *intentions to use*. We feel that these latter findings most likely relate to the fact that HEMS are not presently commonplace within UK households and that discussion of their use was hypothetical. As such, there are no established social norms around ownership nor firm beliefs about the prospective voluntariness of HEMS usage. One could argue that as HEMS become more commonplace that *subjective norms* and *perceived voluntariness* will become more prominent antecedents of *intentions to use*. Indeed, prior research has shown that *subjective norms* in particular are a strong antecedent of *perceived usefulness* and *intentions to use* technology (Schepers & Wetzels, 2007).

Our findings also indicate that *image* (i.e. the belief that social status could be gained from the use of a HEMS) had a positive association with *intention to use* via *perceived* *usefulness.* This is despite the participants tending to disagree that the HEMS would provide them with an increased social status. This disagreement could derive from the relatively private and inconspicuous nature of a HEMS versus more visible energy technologies (e.g. solar panels; Griskevicius et al., 2010), as well as electricity itself being typically “invisible” (p. 6111) and often consumed habitually, without conscious consideration (Hargreaves et al., 2010). Furthermore, there may have been a lack of familiarity with the technology and there was an absence of clear *subjective norms* around ownership. These factors may have contributed to people being doubtful of the *image* benefits that would be afforded by having a HEMS. The positive (mediated) association between *image* and *intentions to use* a HEMS in this study does, though, suggest that should: (a) positive *subjective norms* develop; and/or (b) beliefs about the social status benefits of owning a HEMS strengthen, then this may help to promote their uptake.

Evidence for this can be found in the two year ‘Smart Communities’ project, where a context of community action (including weekly emails emphasising the community aspect of the project) extended individuals’ engagement with smart energy technologies and energy reduction initiatives (Burchell, Rettie, & Roberts, 2016). Similarly, with other novel technologies, such as alternative-fuel vehicles, the social influences of interpersonal communication, social norms and the neighbourhood effect (which is the effect of observing the technology being demonstrated by those in close, physical proximity to you) are known to be important determinants of consumer choice (Pettifor, Wilson, Axsen, Abrahamse, & Anable, 2017) and thus could be predicted to have a similar role in future HEMS adoption.

Another central finding from this study relates to the importance of the internalisation of national energy goals in shaping participants’ *intention to use* a HEMS. We feel that this finding holds relevance for policies designed to increase consumer acceptance and uptake of HEMS. Specifically, the promotion of smart energy technologies in the UK has, to date, typically relied upon messaging that points to the local financial (reduced household bills), general environmental (reduced carbon emissions) or increased household comfort advantages that might come from their adoption (Gangale et al., 2013). There are, though, certain limitations to such promotional strategies, e.g., where people feel that monetary savings are too small to warrant change to their existing habits or where people question the realised environmental benefit that might come from their personal efforts to conserve energy (Goulden et al., 2014; Hargreaves et al., 2010).

While not disputing the relevance of financial, environmental and comfort related messaging *per se* (e.g. the retention of *environmental worldview* as a predictor of *perceived usefulness* in our model exemplifies the benefits that could come from contextualising such technologies in terms of their environment benefit) our findings also point to potential value of efforts to promote greater internalisation of national energy-reduction goals as a means of promoting smart energy technology uptake. Indeed, goal internalisation has been explored as prerequisite of psychological empowerment, a cognitive state in which an individual is motivated and perceives themselves as having the necessary capabilities and control to succeed in shared or personal objectives (Menon, 1999). This may have significance to governments' policy intentions to use smart energy technologies to empower consumers in their consumption of energy (e.g. HM Government, 2017); with a sharing of the energy management goal being critical to an individual's motivation to pursue it.

Goal internalisation was also found to moderate the relationship between *home relevance* and *intention to use*. This suggest that the promotion of the shared goal could provide a means of fostering uptake of a HEMS and demand-side management even among those who are more doubtful for the personal financial value of doing so (Goulden et al., 2014; Hargreaves et al., 2010). For this promotion, creating an autonomy-supportive environment for smart energy technology and DSM (as opposed to one in which individuals feel controlled) will be important. For instance, signals from government about commitments to DSM and support for participating households (e.g. providing options), could enhance perceptions of supported autonomy in the pursuit of new energy behaviours and as such, promote internalised goal pursuit (Lavergne, Sharp, Pelletier, & Holtby, 2010). Indeed, DSM has been found to be more successful in countries with stronger policy commitments to renewable energy (although, the reasons for this are debated: Srivastava et al., 2018). Further, psychological theories of goal pursuit (e.g. Goal setting theory; Locke & Latham, 1994) point to the greater motivational potential of specified, shorter-term goals (e.g. meet specified UK energy-reduction targets) over diffuse, longer-term ones (e.g. combat climate change). We anticipate that understanding interactions between individual and national goals will be increasingly important as smart grid changes are made to the existing electricity grid and energy policies become increasingly reliant on the efforts of active, participatory consumers (HM Government, 2017; Ofgem, 2017).

Limitations

While this study provides fresh insight into the factors associated with *intention to use* a HEMS, there are some limitations to the present study that should be considered if seeking to apply the findings of this research. For example, beyond the fact that this study sought to predict behavioural intentions and not real-world purchase and use behaviours (see literature on the 'intention-behaviour gap' e.g. Kollmuss & Agyeman, 2002), a key issue is that of generalizability. Due to financial restrictions, this study was based upon a self-selected convenience sample and is thus not nationally representative. While some of the biases in the sample (e.g. an over-representation of young, highly educated participants) were recorded, others were not. For instance, we did not assess the extent to which participants had: (a) experience of using other energy management technologies (e.g. smart meters and in-home displays); and/or (b) were interested in the general concept of energy management. Further, we did not directly capture the perceived restrictions that people may experience on their energy consumption, which might reduce their ability or willingness to respond to the price signals (making electricity demand price-inelastic; Zhu, Li, Zhou, Zhang, & Yang, 2018). We argue that in future research it would be prudent to include more measures of items likely to reflect any key recruitment biases (e.g. participants' ownership and use of energy management technologies) and the perceived restrictions on their energy consumption so as to control for them in subsequent extrapolation or dissemination activity.

It should also be acknowledged that while efforts were made to make the contextualising information provided to participants about the HEMS as unbiased as possible (through expert feedback and piloting), the tone of the information was still relatively positive and could have led participants towards forming positive perceptions of the HEMS. This is because HEMS were presented as an enabling technology that could provide solutions to problems associated with household energy consumption. We would argue, however, that HEMS are being designed and promoted with such intent and that the contextualising information we provided is likely to map to that which will likely accompany the promotion of HEMS in commercial contexts. While this might add an additional degree of ecological validity to our study, we feel that it will be of interest in future research to investigate how presenting more explicitly positive or negative argumentation for or against HEMS would influence public acceptance of the technology. Further, goal internalisation, as a component of psychological empowerment, provided novel insights into the acceptance of technologies being promoted by governments and offers avenues for future research (e.g. where these collective and individual goals are found to conflict).

5 Conclusion and Policy Implications

This study sought to investigate individual differences that can explain the observed differences in household engagement with smart energy technologies and demand-side management. Overall, the findings of this study suggest that the practical, design elements to ensure the perceived ease of use of the HEMS will be important for promoting the use of a HEMS, but so too will ensuring the relevance of a HEMS to people's homes and the identification of ways to associate usage of the HEMS with enhanced social status. Further, greater pro-environmental worldviews and internalisation of the energy goal may also offer possible means of promoting engagement. Indeed, these findings suggest the use of shared goals and support the practice of community engagement to enhance the perceptions of energy management technologies and promote individuals' participation and empowerment in demand-side management strategies.

6 CRediT Authorship Contribution Statement

Colin Whittle: Conceptualization, methodology, formal analysis, investigation, data curation, writing – original draft, writing – review & editing, visualization, and project administration.

Christopher R. Jones: Conceptualization, methodology, writing – original draft, writing – review & editing, and supervision.

Aidan While: Conceptualization and supervision.

7 Declaration of Competing Interests

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.

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APPENDICES

Appendix A: Participant contextual information on Home Energy Management Systems (HEMS) and Demand-Side Management (DSM)

Electricity Generation and Use

At the moment most of your electricity comes from large power stations in the UK. These power stations burn coal, gas or use nuclear energy to make electricity. This electricity is then sent to your home using cables so that you can use it to power your house.

Power stations are always making electricity. How much electricity is being made needs to match with how much electricity is being used. Making too much electricity is wasteful, but not making enough may mean your lights go out.

Peaks in Electricity Demand

When a lot of people are using electricity at the same time it is called a peak. When this happens the power stations must increase the amount of electricity they are making. This is so that they make enough to meet everyone's needs. In the UK a peak time is usually in the evening at around 17:30 (5:30pm). This is when people get home from work and begin to cook food or turn on televisions. The graph below shows how the amount of electricity being used goes up and down during a normal the day and night in the UK.

Matching supply with demand

Matching the supply of electricity to the demand for electricity is the job of system operators. They make estimates about how much electricity is going to be needed at a given time of the day and night. These estimates are based on how much is usually needed at that time of day or night. For example, they will estimate there might be more demand at 17:30 in the evening, because there usually is more demand at this time. They then make sure there is enough electricity available at that time.

The system operators have become very good at estimating when electricity use might go up or down. There can still be surprising changes in how much electricity is being used though.

Surprise increases in electricity use are a problem because they mean that the power stations have to work harder to generate the needed electricity. Or more power stations may have to be turned on. This means using more of our oil, coal or gas and extra pollution is made.

Another problem is that predicting electricity use in the future is going to become harder. This is because the way we use electricity is changing.

New technologies in our homes and other buildings will mean bigger and more unpredictable demands for electricity. For example, it is likely that more buildings will start to use electric heating.

This will increase demand for electricity, particularly on cold days. Also, more people may use electric cars, which will increase demand for electricity.

Changes in how we make electricity

Bigger and more unpredictable demands for electricity will make demand harder to estimate. On top of this, changes in how we make electricity are going to make the amount of electricity being made, harder to predict.

Wind energy is already being used to supply some of the UK's electricity and more wind farms planned by the year 2030. We also have increasing amounts of renewable sources of electricity, such as solar power.

Wind and solar power stations do not provide a steady supply of electricity like coal, nuclear or gas power stations do. This is because wind, solar and tidal generators all depend on the weather in order to be able to make electricity. For example, wind farms can only make electricity when the wind is blowing.

Because some renewables are dependent on the weather, increasing the UK's reliance on them to provide electricity could increase the chance that the number of people wanting to use electricity ends up higher than the amount of electricity that can be supplied. This is even more likely at times of peak demands. Greater demand for electricity and a less predictable supply of electricity will make matching supply with demand very difficult. It is important that the system operators are still able to match how much electricity is made with how much is wanted.

To make it easier to match the amount of elect ricity being made to the amount of electricity being used, some new technologies will be needed in your house and you might also have to change how and when you use your electricity in your home.

Real-time Monitoring

In the future, system operators will need to be able to respond faster to changes in the supply and demand levels. This is so that they can keep the balance between the electricity supply and demand.

To help them respond faster to changes the system operators will need to install smart meters in your house. The smart meters will replace your existing electricity meter. These smart meters will provide the system operators with much more accurate and detailed information about your use of electricity.

The information will include how much electricity you are using from one minute to the next. This is called real-time monitoring. It will mean system operators will no longer have to guess about how much electricity you and others are using.

You will also be able to see your own real-time energy usage information via a Home Energy Management Systems (HEMS). Below is a picture of what it could look like.

Real-time pricing

The real-time monitoring of electricity use means that system operators can track how much electricity is being used from one minute to the next by a particular neighbourhood. As the amount of electricity being used in a particular neighbourhood changes, the energy providers can change the price of the electricity in response. This is called real-time pricing.

When lots of people are using electricity at the same time the price of the electricity increases. When fewer people are using electricity, the price decreases. The current 'real time' price of electricity in your neighbourhood will be shown on the screen of your Home Energy Management System. This will allow you to keep track of the price across the day and night.

The graph below shows how the price of the electricity (the blue line) changes as the demand of electricity (the brown line) also changes. As you can see, the price of electricity and demand for electricity tend to go up and down together.

It is believed that real time pricing will help system operators to more accurately match supply of electricity with demand for electricity. It is also expected that if the price of electricity increases, that you (and others in your neighbourhood) will look for ways to reduce how much electricity you are using so that you can save money.

The benefit is that if enough people reduce their electricity use at the same time, then a peak in electricity demand can be avoided.

So, how could real time pricing help you to save money? Some household tasks like using your washing machine use large amounts of electricity. With real time pricing of electricity you could time your use of the washing machine so that it runs when electricity prices are cheaper. For example, you could set your washing machine to start at 3:00 in the morning, when it is unlikely that many other people will be using much electricity and so electricity prices are likely to be cheaper.

Smart meters are already being put in homes in the UK. Real-time pricing has already been introduced in some parts of America. It is currently being discussed by the UK Government and electricity system operators.

Appendix B: Demographic information of participants

B.1 Frequencies for property ownership, property type and educational attainment

	Frequency	%		Frequency	%
Property Ownership			**Educational Attainment**		
Renting the property	38	36.4	GCSE/O-level	7	6.5
Own the property	66	61.7	A/AS level	7	6.5
Other	2	1.9	University Degree	30	28.0
Property Type			Master's Degree	21	19.6
Detached	20	18.7	Doctorate Degree	40	37.4
Semi-Detached	40	37.4	Other	2	1.9
Terrace	29	27.1			
Flats	18	16.8			

N = 107

Appendix C

C.1 Items and scale reliability

Scale	**Items**	**Cronbach's Alpha (α)**
Intention to use HEMS	1. *Given that I have access to the HEMS, I predict that I would use it.* 2. *Assuming I have access to the HEMS, I intend to use it.*	.94
Technology Acceptance		
Perceived Usefulness	1. *Using the HEMS in my house would enable me to control my energy use.* 2. *Using the HEMS in my house would improve my energy management.* 3. *Using the HEMS in my house would increase my ability to control my energy use.* 4. *Using the HEMS would enhance my effectiveness on managing my energy usage.* 5. *Using the HEMS would make it easier to manage my energy use.* 6. *I would find the HEMS useful in my house.*	.97
Perceived Ease of Use	1. *Learning to operate the HEMS would be easy for me.* 2. *I would find it easy to get the HEMS to do what I want to do.* 3. *My interaction with the HEMS would be clear and understandable.*	.93

	4. *I would find the HEMS flexible to interact with.* 5. *It would be easy for me to become skilful at using the HEMS.* 6. *I would find the HEMS easy to use.*	
Voluntariness	1. *I feel my use of HEMS would be voluntary.* 2. *My government does not require me to use HEMS.* 3. *Although it might be helpful, using HEMS is certainly not compulsory for my home.*	.66
Image	1. *People in my neighbourhood who use HEMS have more prestige than those who do not.* 2. *People in my neighbourhood who use HEMS have a high profile.* 3. *Having HEMS is a status symbol in my neighbourhood.*	.87
Home Relevance	1. *In my home, usage of the HEMS would be important.* 2. *In my home, usage of HEMS is relevant.*	.93
Subjective Norm	1. *People who influence my behaviour would think that I should use HEMS.* 2. *People who are important to me think that I should use HEMS.*	.86
Goal internalisation	1. *I am inspired by the energy reduction we are trying to achieve in the UK.* 2. *I am inspired by the energy reduction goals of the UK.* 3. *I am enthusiastic about working towards lower energy usage in the UK*	.72
Environmental worldview	1. *We are approaching the limit of the number of people the earth can support.* 2. *Humans have the right to modify the natural environment to suit their needs.* 3. *When humans interfere with nature it often produces disastrous consequences.* 4. *Human ingenuity will insure that we do NOT make the earth unliveable.* 5. *Humans are severely abusing the environment.* 6. *The earth has plenty of natural resources if we just learn how to develop them.* 7. *Plants and animals have as much right as humans to exist.* 8. *The balance of nature is strong enough to cope with the impacts of modern industrial nations.*	.84

Scales: TAM2 = 1- 7; Goal internalisation, perceived ability to influence others, and perceived competence = 1-6; Environmental worldview= 1-5. Higher scores on all scales coded to indicate greater agreement.

Appendix D: Estimates for moderated model

D.1 Standardised coefficients from the mediated-moderated model.

	Perceived usefulness	**Intention to use**
Perceived usefulness	-	**.58*** **
Perceived ease of use	**.29*** **	-.02
Perceived voluntariness	-.01	-.02
Image	**.17***	-.06
Home Relevance	**.57*** **	**.32** **
Subjective norm	-.01	-.03
Goal internalisation	**-**	.05
Environmental Worldview	**.15***	-.01
Goal internalisation x Home relevance	**-**	**-.11** **
Constant	<.01	.06
	$R^2 = .73, F(6, 100) = 45.14$ $p < .001$	$R^2 = .84, F(9, 97) = 58.79$ $p < .001$

**p*< .05, ***p* <.01, ****p*<.001. *P* values < α = .05 are emboldened. Standard error estimated from a bias-corrected bootstrap sample of 10,000.
Model estimated using model 5 of the statistical software PROCESS (Hayes, 2017)