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Exploring acceptance of decentralised energy storage at household and neighbourhood scales: A UK survey

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ABSTRACT

Effective deployment of Distributed Energy Storage (DES) will depend in part on public attitudes and acceptance at both community and household levels. Here, we present the results of an exploratory survey to understand prospective public acceptance of DES technologies at household and community level in the UK ($N = 949$). The research design draws on previous qualitative technology acceptance work that was undertaken to inform the survey. We show that while the level of awareness of DES among the UK public is still very low, initial evaluation of information on domestic and neighbourhood battery storage is positive and evokes positive feelings that are significant predictors of positive attitudes. Moreover, the UK public has strong expectations about the technology, its benefits and its management. In particular, the results point to a bounded and place-based role for altruism: that people are more likely to accept energy storage facilities in their neighbourhood if they are for the benefit of that same neighbourhood. The results help us to understand public expectations of the technologies and the institutions relevant to decentralised energy design and deployment by commercial and public sector actors, as well as having implications for policy design and communication strategies.

1. Introduction

There is increasing interest in the role that distributed energy storage (DES) for both electricity and heat might play in a future energy system (Bale et al., 2018; Dodds and Garvey, 2016; Taylor et al., 2013). For the UK to be able to reach the target of net zero greenhouse gas emissions by 2050 (The Climate Change Act, 2008, 2019) radically different ways of producing and consuming energy will be required, including a greater role for decentralised energy systems.

DES is generally viewed as a class of technologies that can facilitate the path towards decarbonisation of the energy system (Gaede and Rowlands, 2018; Grünewald et al., 2011). In recent years, it has received increased attention in both government policy and strategy (BEIS, 2017, 2018). DES at both community and household levels offers new opportunities for citizens, enabling the production, consumption and storage of locally produced energy (Koirala et al., 2016, 2018). It can also help with electricity network congestion and provide various system services. DES may also offer greater value to the overall energy system than grid-connected storage due to its ability to provide services to both transmission and distribution networks (Pudjianto et al., 2014) Accordingly, many local governments have ambitions to deliver local energy projects to contribute to the transition to a low-carbon society (Bale and Roelich, 2015) that include DES (Margaret Tingey et al., 2017; Taylor et al., 2013), to the benefit of householders and communities. Significant efforts are also being made to progress technological and business model innovation in the sector (Burlinson and Giulietti, 2018).

Here, we present the results of a quantitative study of prospective public perceptions of battery storage in the UK, using a nationally

Abbreviations: CES, Community Energy Storage; DES, Distributed Energy Storage; NG, National Grid.

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representative sample (n = 949) split into two groups: those answering questions relating to installations at the household level and those relating to neighbourhood/community[1]-level systems. Understanding public perceptions of battery and other forms of storage is essential for the progress of the sector (EUROBAT, 2016; van der Stelt et al., 2018), yet public voices have been little studied in this context to date (Devine-Wright et al., 2017). Our survey instrument is based on an adapted version of the extended technology acceptance model of Huijts et al. (2012), with the main adaptation being the addition of questions relating to environmental self-identity, values and related questions that seek to distinguish benefits for the self and others. The latter draws on prior qualitative work on DES, undertaken in part to inform the survey design (Ambrosio-Albala et al., 2019). Hence, the aim is more to explore the possible role of environmental identity and altruism within the broad framing developed by Huijts et al. (2012) than to fully reproduce the latter model. Given that the key secondary aim is to explore the relative significance of the variety of factors hypothesised as potentially important, stepped multiple regression is used, to incrementally test possible models.

2. Background and literature review

2.1. Reasons for assessing public acceptance of DES

Focusing here on electricity storage, public acceptance of DES will be required to meet carbon reduction targets both at the European (EC, 2012), national and local level (BEIS, 2017, 2018). As energy storage can be integrated at different levels of electricity supply grids, it is able to provide valuable services across the energy chain so benefitting users at different levels and the system as a whole. These services include the potential to reduce the level of curtailment of distributed renewable technologies (Sidhu et al., 2018), such as solar PV and the provision of flexibility services to distribution grids, such as low voltage substation and network reinforcement, and voltage management (UKPN, 2018). Distributed storage also has the potential to supply non-electrical end-uses, notably heating and mobility (EASE and EERA, 2013; OFGEM, 2018) and provide a new source of revenue that can be captured by innovative business models (Jones et al., 2016).

While much of the focus of both academic research and actual deployment has been on the use of batteries at a household level, the role of community energy storage (CES) should not be ignored. Based on a survey of the literature (Parra et al., 2017), highlight a number of advantages that CES could bring over single-home systems, including: enhanced performance of battery systems due to smoother electricity demand profiles resulting from aggregation of household loads, a reduction in the required energy and power ratings of the storage system in terms of kWh/home and kW/home, and potential economies of scale from to the use of larger systems.

The market for domestic-scale electricity storage technologies in the UK has grown rapidly over the last few years, but from a very small base. This expansion has been driven by the uptake of domestic solar PV, falling battery costs and, more recently, new innovative customer propositions such as time of use tariffs and domestic energy trading platforms. As a result, a large number of players are now in the market, including established energy names such as such as Shell, BP, E.ON EDF, and other well-known brands including Tesla and Duracell (Charles, 2019)). A number of pilot schemes, such as SoLa Bristol (Western Power Distribution, 2016) and Project Eric (ERIC Project, 2015)have been completed, helping to build an understanding of the value that battery storage can bring to users in practice. The UK government is now investing over £100 m in industry and researchers to develop smart local energy systems, with a number of demonstrators recently announced all of which incorporate some form of DES (UKRI, 2019). The government has also devolved more scope for action for implementing climate change policies and strategies, such that the involvement of local authorities is expected to increase (BEIS, 2019) with a concomitant focus on local energy solutions. Ultimately, however, for the deployment of DES to move from its current situation of early adopters and pilot projects to a mass market will significantly depend upon the attitudes of the lay public as users of the technology, particularly when this requires their active involvement (EC, 2012). It is for this reason that we focus here on public perceptions of energy storage and associated policy relevance.

2.2. Studies of public perceptions of energy storage

While Taylor et al. (2013) set out the likely issues relating to public acceptance of energy storage technologies, their assessment is based on inference from the wider knowledge base on energy acceptance issues. There are very few publicly available empirical studies of public perceptions that are specific to residential and neighbourhood-scale batteries. The small literature that exists is also geographically-specific: for example (Abe et al., 2015) focus on Japan and (Romanach et al., 2013) on Australia. The latter studies address consumer perceptions of PV and energy storage broadly, as well as issues relating to batteries at the household level (i.e. participation in distributed energy markets, understanding of the technology, ownership of the electricity storage systems), quantitatively and qualitatively respectively. In the UK, in-depth qualitative research on public perception of batteries both at household and community level was undertaken by (Ambrosio-Albalá et al., 2019). The latter study indicates the significance of trust-related perceptions relating to the national government and the municipal authority in likely acceptance of battery storage. In particular, both national and local government are seen as desirable, key actors in delivering information and support. Participants took the view that local authorities should be involved in the practical aspects of adopting a battery, whereas the national government should provide credible information on the technology. This study also corroborated Huijts et al. (2012) in that a lack of trust in public institutions, often based on previous experience, was found to be a significant influence.

Given this, the present study investigates the variety of variables potentially involved in motivating the lay public to adopt and accept battery storage technologies (Agnew and Dargusch, 2017), and moreover aims to provide more precise estimates of the extent to which these variables account for prospective acceptance of DES. The specific measures are described in section 3 and are accompanied by Appendix A Survey Design Instrument. While it should be emphasised that the study is of hypothetical adoption under specified assumptions, it nonetheless sheds light on UK public perceptions of the expected benefits to be derived from the technologies, consumer willingness to invest, and expectations regarding involvement from the public and private institutions. In this regard, the study is intended to be of value for the public-facing aspects of DES planning, deployment and policy.

3. Methodology

A questionnaire survey of a nationally representative sample of the UK public was undertaken in February 2018, to assess the acceptance of DES technologies, specifically batteries, at both household and community (neighbourhood) levels. Question phrasing and accompanying information are provided in Appendix B Questionnaire. Question design incorporates aspects of the enhanced technology acceptance model of Huijts et al. (2012), adapted for battery technology and with a different emphasis; the variables selected for investigation are described in section 3.2.1. Given the underlying rationale of the model developed by

[1] We are aware that community and neighbourhood are not always synonymous. The idea of community is constituted by a set of social relationships of a group of people. At the same time, it also implies localism and is used to refer to types of population settlements (such as neighbourhoods). For this research both terms will be used indistinctively.

Huijts et al. (2012) acceptance is understood in behavioural terms. The Huijts et al. (2012) model is a combination of the theory of planned behaviour (TPB) (Ajzen, 1991; Ajzen and Fishbein, 2005; Fishbein and Ajzen, 1975) and the norm activation model (NAM) (Schwartz, 1977a; Schwartz and Howard, 1981)., (De Groot and Steg, 2009).

The TPB has been applied in a very wide range of contexts and is based on the premises that people are more likely to intend to undertake a behaviour (in this case, accept or install energy storage technology) if they believe: (a) that this will have an outcome that they view as positive (positive attitudes); (b) that significant others will approve of that behaviour (consistency with internalised social norms); and (c) that the behaviour will be effective in achieving the outcome (positive control beliefs). Whereas the TPB conceives of behaviour as directly related to a wilful intention to behave that follows from (a-c) above, the NAM (Schwartz, 1977b) singles out the role of norms, experienced as feelings of moral obligation to act. Most studies set the NAM in the broader context of additional variables, notably the perception (awareness) that there is a problem and the belief that one has some degree of responsibility for responding to it (Schwartz and Howard, 1981).

Following the above, in the model of Huijts et al. (2012), it is assumed that acceptance behaviour is influenced by: evaluative attitudes (how battery acceptance is viewed by oneself); subjective norms (how one thinks significant others view one's potential battery adoption); and perceived behavioural control (how difficult battery adoption is believed likely to be). Here we substitute questions on subjective norms with questions on environmental identity and related values, to investigate these as possible influences on battery adoption, as well as variables relating to place attachment and sense of belonging, which can also precede particular attitudes where changes to physical localities are involved (Evensen and Stedman, 2017). In addition, specific attitudes are also often involved in corresponding, specific behaviours; hence we also include specific attitudinal questions relating to perceived costs, benefits, as well as questions on a variety of expectations, which function as beliefs. Versions of the theory of planned behaviour and the norm activation model have been well-researched in pro-environmental behaviour contexts, whereas environmental self-identity has been less so. Hence the decision to deviate from the Huijts et al. (2012) model in an exploratory design. Moreover the specific selection of variables has proved previously useful for the study of in-home hydrogen technology acceptance (Bögel et al., 2018), where the aim was similarly not to build a structural model of acceptance per se, but to investigate the relative significance of possible causal variables.

3.1. Participants

The survey was nationally-representative for the UK (n = 949). The sample consisted of panel members of non-technology users recruited by a market research company and was gender and age balanced; 48.8% of participants were male and 51.1% female. Participants were part of online panels retained by the market research company and received compensation for their time. Appendix C gives the sociodemographic profile of respondents in the survey (Tables C1 and C2). The survey was set up electronically and participants could complete it in circa 20 min.

3.2. Survey instrument design

3.2.1. Questions and items

The participants responded to a series of hypothesised scenarios, in relation to energy storage adoption and acceptance of community energy storage. As presented in Appendix B the questionnaire and sample were split into two sections, relating to household and community storage respectively (Fig. 1). In order to have an informed evaluation by the participants, respondents received information about energy storage and distributed energy storage technologies, their benefits and the potential risk they might entail (Fig. 1).

All respondents completed core questions as follows. The first core section included questions to capture the uninformed evaluation of energy storage and distributed energy storage technologies (batteries). After this, another core section of the questionnaire included five questions to test informed evaluation of technologies. Following this, the sample were randomly split into two groups to answer questions: half of the sample answered questions about battery technologies at the household level (n = 483) while the other half answered questions about community energy storage (CES)(n = 466) (Appendix C Table C2). In both sections, the questions test informed evaluation of household or community energy scenarios. The questionnaire then returns to core questions, with the complete sample answering questions about values, trust, environmental self-identity and lifestyles, and involvement with

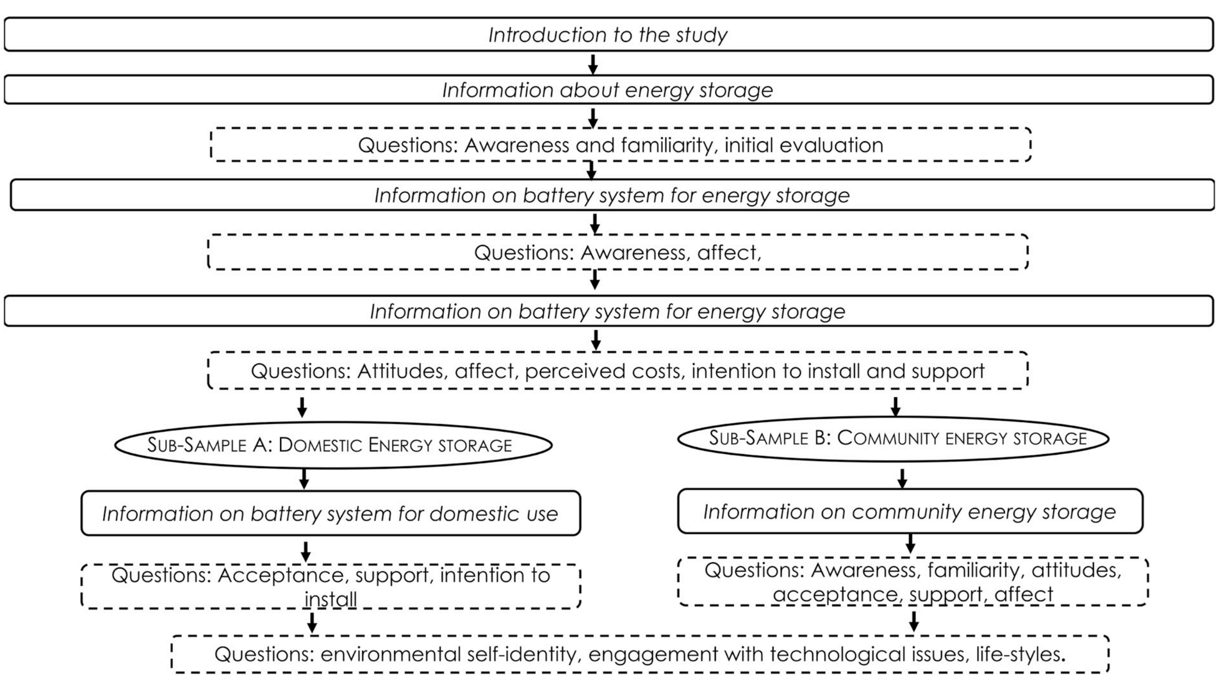

Fig. 1. Questionnaire design.

technological issues. More information about the survey instrument design and the questionnaire measures is included in Appendix A.

3.3. Data analysis

Descriptive statistics are initially provided on the level of acceptance or opposition to the deployment of CES projects and in-home battery systems. This is followed by hierarchical regression in 3 steps using list-wise deletion, including control variables to account for whether the respondents answer the section on CES or household level.

In the first step of the regression analysis (model 1), socio-demographic variables (gender, age, education, and high level of education) were regressed on the likelihood to have a battery system storage at home, given equal price, comfort and maintenance costs (Question 8 (1)); intention to install the battery and paying for the total costs (Question 8 (2)); willingness to invest in a battery when the benefits are for the household (Question 9); willingness to invest in a battery when the benefits are for the National Grid (NG) (Question 11(1)) and both the household and NG(Question 11(2). In the second step (model 2) a set of perceived benefits, costs and expectations of the technology, global attitude, and affect variables were included; finally, in the third step variables measuring attitudes, values and beliefs (trust in government and industry, involvement of technological issues, pro-environmental self-identity and values orientation) were added in the regression analysis (model 3). The rationale for this sequence is to build to and beyond a quasi-theory of planned behaviour-type model. That is, to start with basic variables and then add nuance and narrow down.

4. Results

In this section, domestic battery storage is considered first and community battery storage thereafter. For each case, descriptive statistics are presented before regression models, with the latter taking three consistent forms throughout the analysis and regressed against different dependent variables. Throughout the exploratory results section, we refer to statistically significant predictors.

For clarity, we have included a graphical summary after every exploratory model carried out. In the relationship between the variables, we include the standardised Beta coefficient between the predictor and the outcome variable. The first model type is based solely on demographic variables; the second model adds awareness, knowledge, beliefs of consequences and affective attitudes; the third adds additional attitudes (including trust), technology-related motivation, pro-environmental self-identity and environmental values. To pre-empt the findings, it seems that the core elements of the theory of planned behaviour (Ajzen, 1985) account for most of the variance observed.

4.1. Household battery storage

4.1.1. Awareness and acceptance of domestic energy storage

The first section of the survey included questions concerning energy storage. First, we report on descriptive statistics, followed by the results of the regression analysis.

As mentioned, questions for energy storage as a whole were answered by the total sample (N = 949). After providing information about energy storage, people were asked a set of questions on awareness, familiarity and initial evaluation of the technology at the household level. Levels of awareness were very low and the percentage of people who said that they had heard of storage for renewable energy before the survey was 38%. By gender, we observed that higher levels of awareness were found in males (34% were aware) compared to 27% of women who were aware. In terms of familiarity, approximately 66% of the respondents would rate themselves as slightly familiar with energy storage and 16% not at all familiar with it (Table C3).

In terms of the initial evaluation of the technology after being provided with information, 40% of participants consider storage for renewable energy a good solution for environmental challenges, and almost a further 30% out of the total respondents rated it as a very good solution (Table C4). Regarding battery systems specifically, 77% had not heard about battery systems for energy storage at the household level, before participating in the survey. The overall informed evaluation of domestic battery storage is low to neutral: women tend to be more neutral about their attitudes towards batteries-although the difference is less than 2%, while only around 17% of the male respondents see batteries as a good or very good solution (Table C5).

Regarding consequence-related expectations of batteries, almost half of the respondents have neutral feelings about the effect on the environment. Beliefs about a battery being affordable on the respondent's budget are slightly more negative, and people tended to expect that a battery system would not be affordable on their budget. Neutral positions were revealed as to the extent to which batteries were seen as likely to make life easier for the respondents (Fig. 2). Percentages are distributed equally gender-wise.

After measuring global attitude and perceived benefits, costs, and risks, people were asked about their intention to install and support government interventions. Three different conditions were tested: i) equal price, comfort and maintenance costs relative to the respondents' status quo; ii) total cost to be paid by households; iii) public funding to subsidise the purchase price of a battery system. Around 34% of respondents agree with the first assumption, and 13% strongly agree. The level of undecided respondents was relatively high under the condition that they would need to bear the total costs and almost half strongly disagree or disagree with installation under that condition. Finally, around 47% of the respondents agree or strongly agree that public funding should cover the total price of the battery systems (Fig. 3). When it comes to differences by gender, a higher percentage of men would be interested in having a battery at home if cost and comfort would remain the same.

Willingness to invest in a battery was also tested under two different conditions, namely: i) benefits exclusively for the NG, and ii) benefits for both NG and personal reward. In general, participants were not willing or undecided to invest in a battery system under the first condition. However, nearly half of the respondents would be somewhat willing to invest if they were financially rewarded. The percentage of undecided participants is higher among women than among men for both cases (Table C6 and C7).

4.1.2. Exploratory models: domestic battery storage

4.1.2.1. Global attitude. Firstly, a model of *global (i.e. general) attitude* toward domestic energy storage was tested by performing a hierarchical regression model in 3 steps (Table C8). First, socio-demographic variables (gender, age, education, and the highest level of education) were regressed on global attitude. In the second step (model 2) benefits, costs and expectations of the technology, initial evaluation and familiarity with energy storage, and affect variables were included; finally, in the third step variables measuring attitudes, values and beliefs (trust in government and industry, involvement of technological issues, pro-environmental self-identity and values orientation) were added in the regression analysis (model 3). Model 1 (demographics) accounted only for 0.6% of the total variance. Model 2 increased the predictive capacity by 37.4%, accounting for 43.6% of the total variance. Model 3 increased the variance explained by a further 2.8%, accounting for 46.4% of the total variance. All three differences and models are significant at $p < .001$.

The global attitude toward energy storage is not significantly predicted by any sociodemographic variables when regressed together with the rest of the predictors. However, in model 1 and 2 gender negatively predicts attitude to energy storage.

For the whole set of variables, global attitude is positively predicted by perceived environmental benefit, initial evaluation of energy storage,

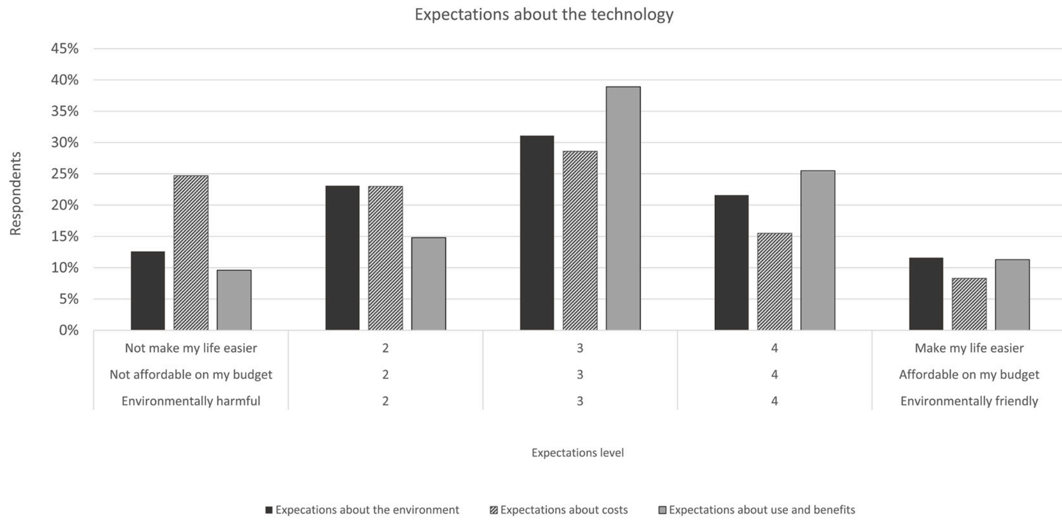

Fig. 2. Expectations about battery system at the household level.

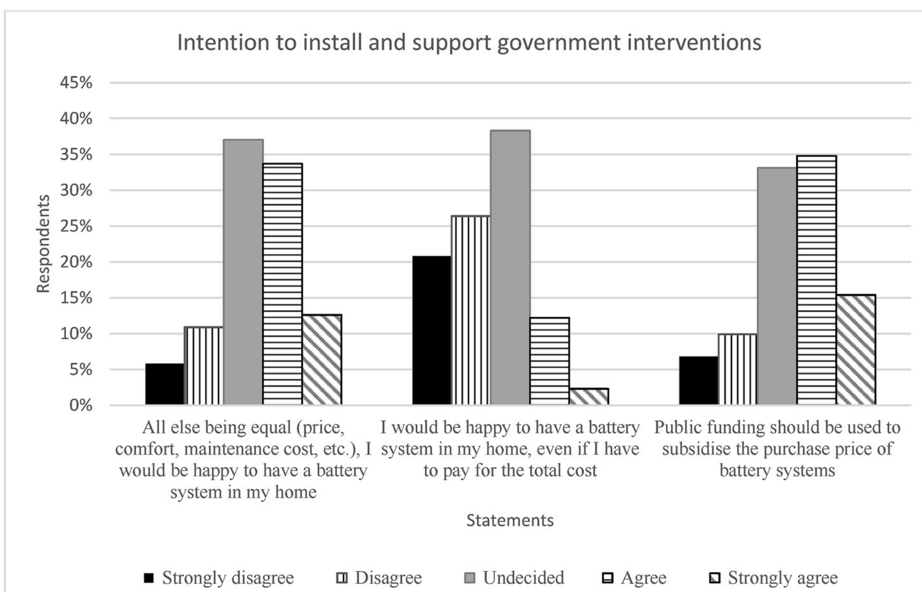

Fig. 3. Intention to install and support.

positive affect towards energy storage, and trust in the industry. On the other hand, global attitude is negatively predicted by negative affect towards energy storage. Appended Table C8 provides more detail on the statistical associations; Fig. 4 shows significant predictors to General global attitude.

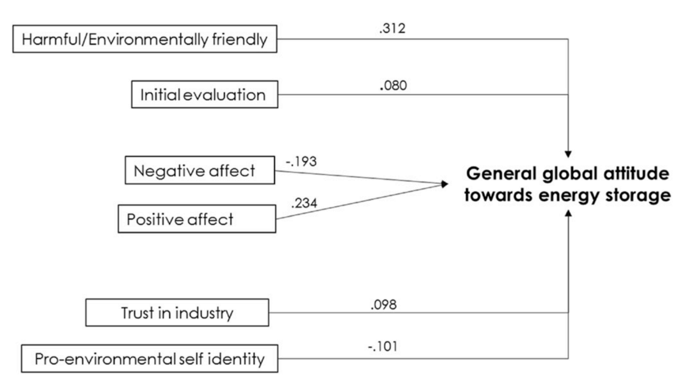

Fig. 4. Global attitude towards energy storage.

4.1.2.2. Installation and investment intention for domestic energy storage

4.1.2.2.1. Including attitudes to benefits. Regarding intention to install a battery storage system at home, Model 3, including variables relating to beliefs, attitudes and values, accounts for 56.2% of the total variance explained. However, the difference between model variance explained is significant only at $p < .05$. Variables such as age, affordability, making life easier, global attitude and both positive and negative affect are significant predictors at $p < .05$. Negative affect towards the technology and age were the only negative predictors for this case (Table C9 Appendix C).

4.1.2.2.2. Assuming equal costs. Regarding intention to install a battery system, keeping costs and risks equal to the status quo, sociodemographic variables account only for 5.9% of the total variance (model 1). Model 2 accounts for 59.3% of the variance while adding variables values, attitudes and beliefs add little. All three model are significant at $p < .05$. Sociodemographic variables also explain little of the total variance of intention to install and pay for the total cost of the battery. Adding perceived benefits of the technology and expectations, global attitude, and affect variables into the model (model 2) increase the percentage of variance explained by 37.7%, such that model 2 accounts for 43% of the total variance of the model. Model 3 including attitudes, values and beliefs accounts for 44.8% of the total variance explained being significant at $p < .05$. In terms of predictors (Fig. 5), positive predictors are age, perceived benefits (the technology being affordable), global attitude and positive affect. Negative affect towards the technology is a negative predictor of the intention to install, under the condition of having to pay for the total cost (Table C9).

4.1.2.2.3. Including perceived benefits. For the willingness to invest in a battery when the benefits are for the household, model 2 (including socio-demographic variables and perceived benefits and costs of the technology and expectations, global attitude, and affect variables) accounted for 49.6% of the variance. Adding beliefs, values and attitudinal variables (model 3) accounted for 50.2%. The difference in variance explained between model 1 and 2 is 46.8% and is significant at $p < .05$. However, the difference between model 2 and 3 barely increased the predictive capacity of the model. Significantly predictive variables for the willingness to install the battery system when benefits are for the household are: age, gender, being and not being affordable, making or not making the life easier, global attitude and positive affect (positively) and negative affect (negatively) (p values are in Table C10 appended).

Willingness to invest in a battery system when the benefits are for the NG is positively predicted by: an egoistic value orientation-contrary to what one could expect-, trust in the industry, positive affect, global attitude, perceived benefits in terms of the technology making life easier, and negatively by age. In that scenario, model 2 accounted for 24.2% of the variance. In line with this, model 3 accounted for 29.7%. Again, there is a minimal difference in variance between model 3 and 2 (1.2%) being significant at $p < .05$; this difference is 20.6% for model 2 and 1.

In the scenario where the benefits were for both supporting the NG and the household, positive predictors were perceived costs, being affordable or not affordable, making life easier, global attitude, positive affect, and trust in the industry. As shown in Fig. 6 negative predictors were: trust in government, negative affect and age. Model 2, socio-demographic variables and perceived benefits and costs of the technology and expectations, global attitude, and affect variables, accounted for 43% of the total variance, significant at $p < .05$. This means an important increase compared to the 4.1% of variance explained of model 1. Model 3, however, did not add much concerning the predictive validity of the model2 (Appended Table C10).

4.2. Community energy storage

4.2.1. Awareness and acceptance of community-level battery storage

This section provides descriptive statistics on the battery storage option at community level. A total of 466 participants responded to questions about CES (Table C2). Following the same rationale as for the domestic energy uses, participants were provided with information about CES and questioned about global attitude, acceptance, support and affect. The level of awareness of CES was found to be very low, with c.43% of the respondents not having heard about it before and 12% only a little (Appended Table C11).

Distribution of responses was equal between positive and neutral global attitude towards CES. As shown in Table A11, the distribution of responses is the same among men and women. When participants were asked about voting for or against it, the highest level reported was slightly in favour (38%), followed by a neutral inclination (33%). On the basis of the information provided, 45.5% of respondents were undecided about neighbourhood battery storage being beneficial for the community, but 34% of the respondents agreed that it could benefit the community. A similar percentage agreed that their living area could be suitable for having a battery installed. As for the previous case, a similar distribution of responses was found for the case of people not being willing to imagine having a battery at the end of their street (Fig. 6). Few differences were found among those agreeing, disagreeing and being undecided. Regarding support for government initiatives, around 41.2% of respondents agreed that public funding should be used to subsidise the purchase and installation of these systems and 37.8% of respondents considered that local authorities should promote the installation of battery systems in every community (Fig. 7).

Participants were also asked about which institutions should promote community battery storage: energy companies, the Government or local authorities. In the case of energy companies, 43% of the respondents agree that they should be in charge of encouraging CES initiatives. The percentage of participants agreeing that the Government or the local authorities should take responsibility is very similar. However,

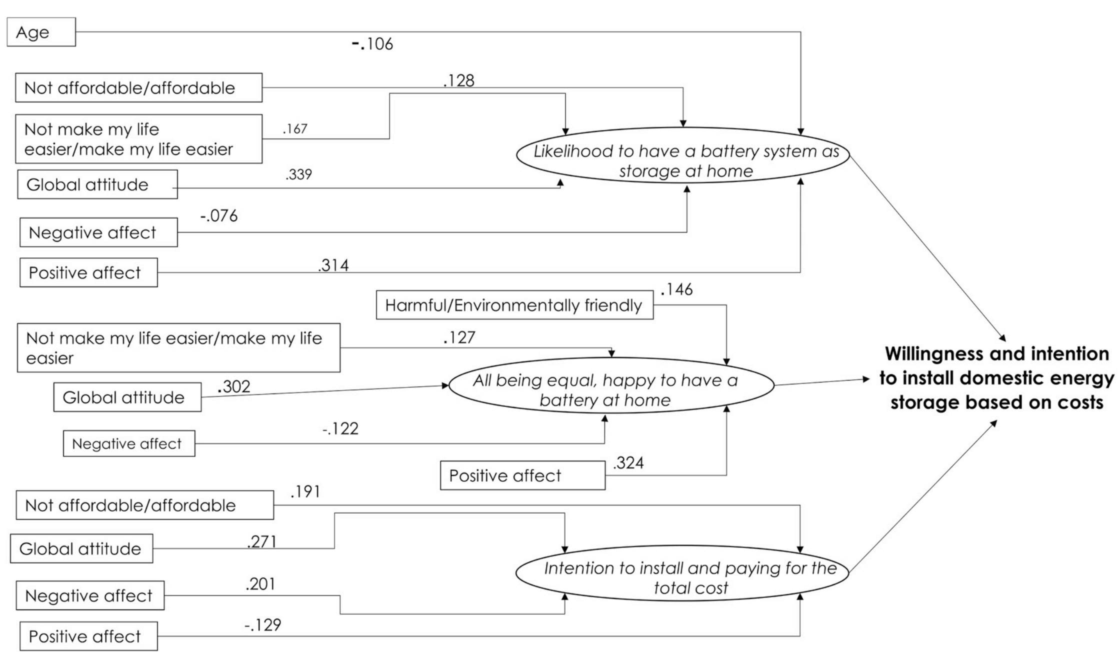

Fig. 5. Willingness and intention to install domestic energy storage based on costs.

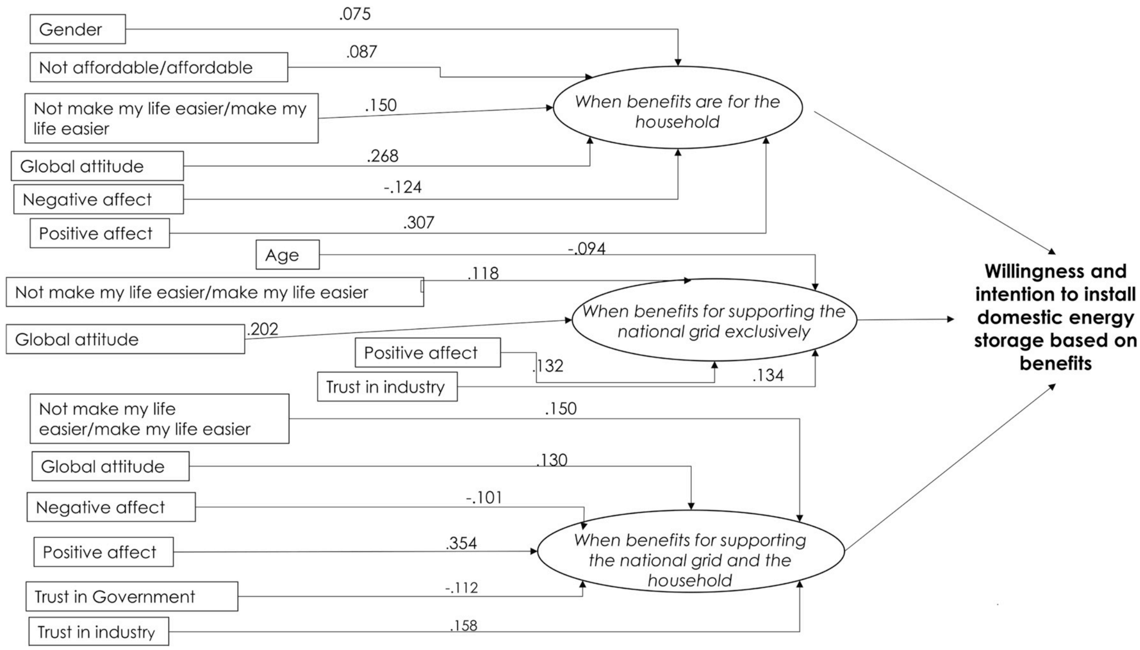

Fig. 6. Willingness and intention to install domestic energy storage based on perceived benefits.

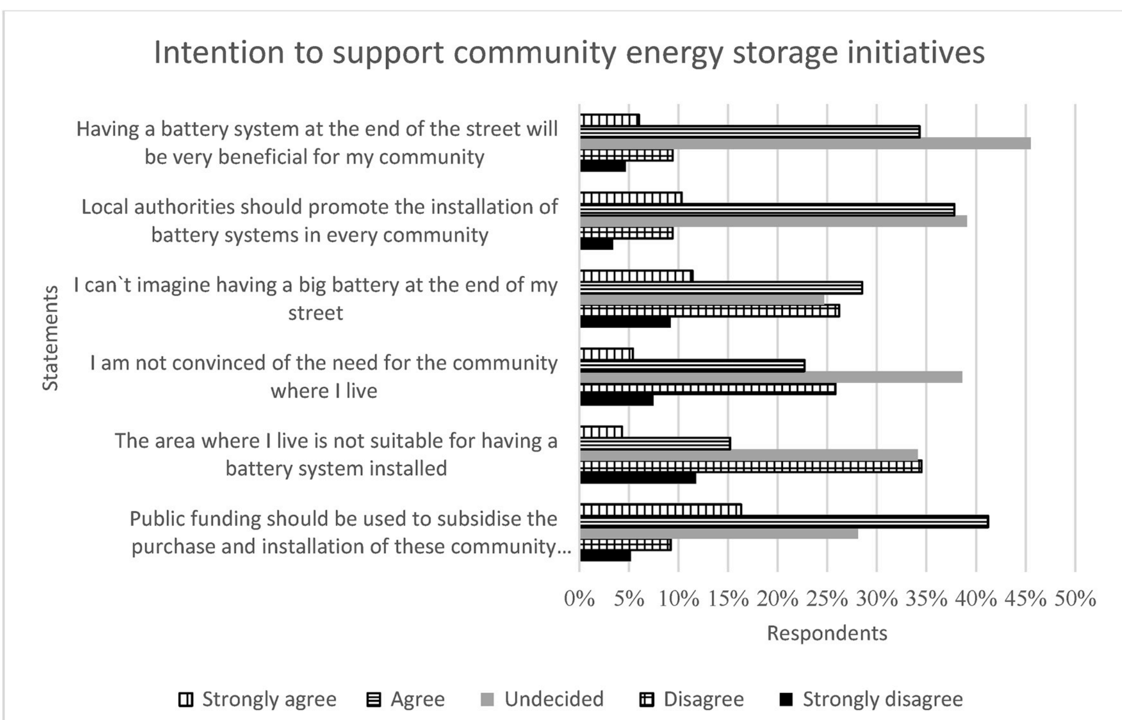

Fig. 7. Intention to support community energy storage initiatives.

the percentage of respondents who were undecided on this topic is high for all three conditions (Appended Table C12).

Participants were also asked about their support for CES based on who would benefit from it, whether the individual community members (households) or the community as a whole. People were more willing to have a battery system at the end of their street if the whole community would benefit from it (41% of participants would be somewhat willing and c.13% totally willing). This is similar for both men and women, for whom response percentages are around 27% for males (somewhat willing and totally willing) and 25% for females (Table C13 Appendix C). In the scenario in which only the individual households would benefit, the percentage of people somewhat willing or willing is 24.2% and 5.4% respectively. The pattern is again similar for both females and males (Appended Table C13).

Finally, the acceptance of these arrangements was also queried, based on the institution that should own and manage them: local authorities, private companies, or private companies and the community. In general, participants reported a higher level of neutral values. In the case of the local authorities, however, both men and women showed strong support (Table C12 appended). The respondents would be less supportive of management and ownership options if the lead organisation was a private company: opposition to CES under this condition was found in 21% for men and 16% for women (Appended Table C14).

4.2.2. Exploratory models: community energy storage

In order to understand acceptance and attitudes with regards to CES based on perceived benefits, a hierarchical multiple linear regression analysis of 3 steps was again conducted (appended Table A15). Predictors in the first step of the model (model 1) were socio-demographic variables (gender, age, education, and a high level of education). In the second step (model 2) a set of perceived benefits, costs and expectations of the technology, global attitude, and affect toward CES variables were included. In the third step of the regression analysis (model 3), variables testing attitudes, values and beliefs (trust in government and industry, the involvement of technological issues, pro-environmental self-identity and values orientation, sense of belonging and place attachment) were included.

As expected, the global attitude towards CES is positively predicted by positive affect towards it and negatively predicted by negative affect (Fig. 8). In terms of sociodemographic variables, age is a significant negative predictor for both model 1 and 2. However, age loses its predictive validity when attitudes, values and beliefs variables are regressed into the model, suggesting that age is to some extent simply a co-correlate.

In terms of variance explained, model 1, including sociodemographic variables, only accounts for 4.8% of the total variance. Introducing perceived benefits, costs, and expectations into the model increases its predictive capacity by 51% (model 2 accounted for 55.9% of total variance), this percentage is meaningfully low for model 3 (the increase is only 0.04%). All three models are significant at $p < .05$.

Attitudes were also tested by asking participants whether they would vote in favour of a CES initiative in their community. Model 1, including exclusively sociodemographic variable, accounted for 3.9% of the total variance. Adding the variables for model 2 increases its predictive capacity in 60.9%; it accounts for 64.8% of the total variance explained for the model, being significant at $p < .05$.

As for the case of global attitude, age was a significant negative predictor in model 1; however, in the other two cases, only affect towards the technology and pro-environmental self-identity are significant predictors. Both positive affect and the latter variable positively predict voting in favour of a CES initiative, while negative affect does so negatively (Appended Table C15).

4.2.2.1. Installation

4.2.2.1.1. Including beneficiary type. We explored *Willingness to have a battery system installed in their local area/community* based on benefits in two different scenarios: (i) when benefits were direct to the community as local projects; and (ii) benefits exclusively for individual households (Appended Table A16). In the first case, sociodemographic variables and perceived benefits, costs and expectations of the technology, global attitude, and affect towards CES (model 2) accounted for 52.5% of total variance explained; increasing the model's predictive capacity by 49.9% beyond model 1. Model 3 accounted for 55.4% of the total variance explained. Each model is significant at $p < .05$. Age and negative affect towards the community are significant negative predictors, whereas positive and altruistic value orientation positively predict acceptance of CES when the benefits are for the community (Fig. 9). Acceptance of CES when benefits are for individual households are significantly and positively predicted by the perceived benefits and expectations of battery storage being affordable, the global attitude towards CES and positive affect. Negative affect and age are negative predictors. Differences between model variance are significant at $p < .05$, but overall the percentage of variance explained is low: model 2 accounts for 21% and model 3 for only 23.4%.

4.2.2.1.2. Including promotion and ownership of community energy storage. Acceptance was also measured through willingness to have a battery system installed in your area/community based on the institution in charge of the promotion of these initiatives: i) local authorities, ii) Government, iii) energy companies. For the first case, acceptance is positively predicted by positive affect towards the CES initiatives *and* negatively by negative affect (Appended Table C17). Model 2 accounted for 49.4% and Model 3 for 49.9% (significant at $p < .05$). Model 3 does not increase the predictive capacity of model 2 significantly.

When the institution in charge of promotion is the Government, positive predictors are perceived benefits and expectations (making the life easier) and positive affect; negative affect towards CES negatively. Age and highest educational level completed were significant predictors when regressed with no other variables (model 1). Model 2 accounted for 46.5% of the variance; model 3 accounted for 47.1%, but this difference is not significant at $p < .05$.

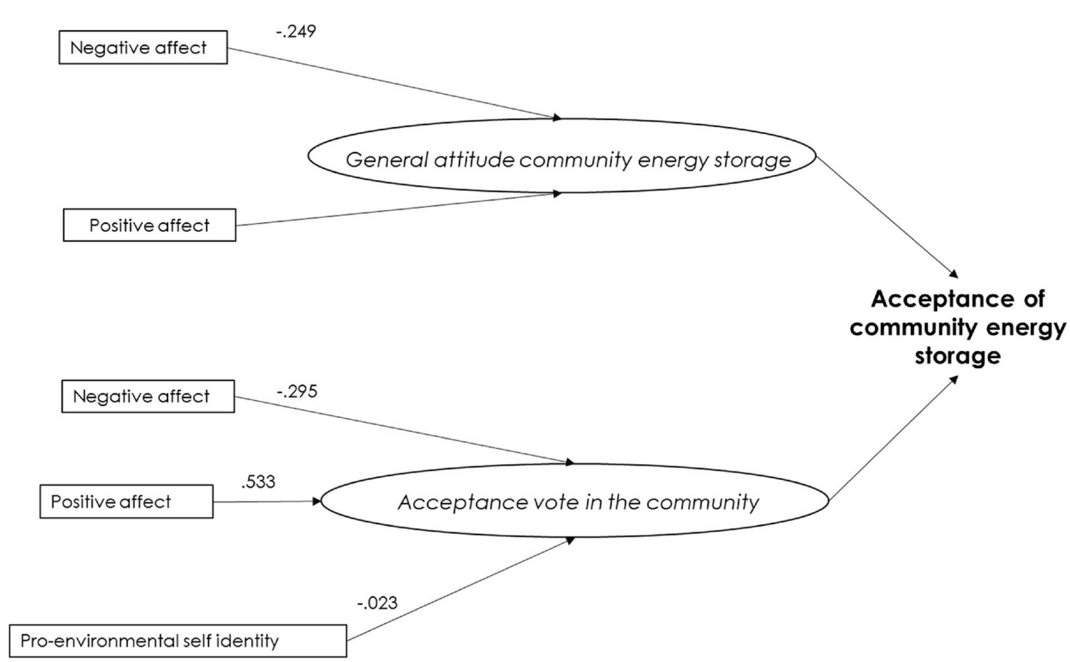

Fig. 8. General acceptance of community energy storage.

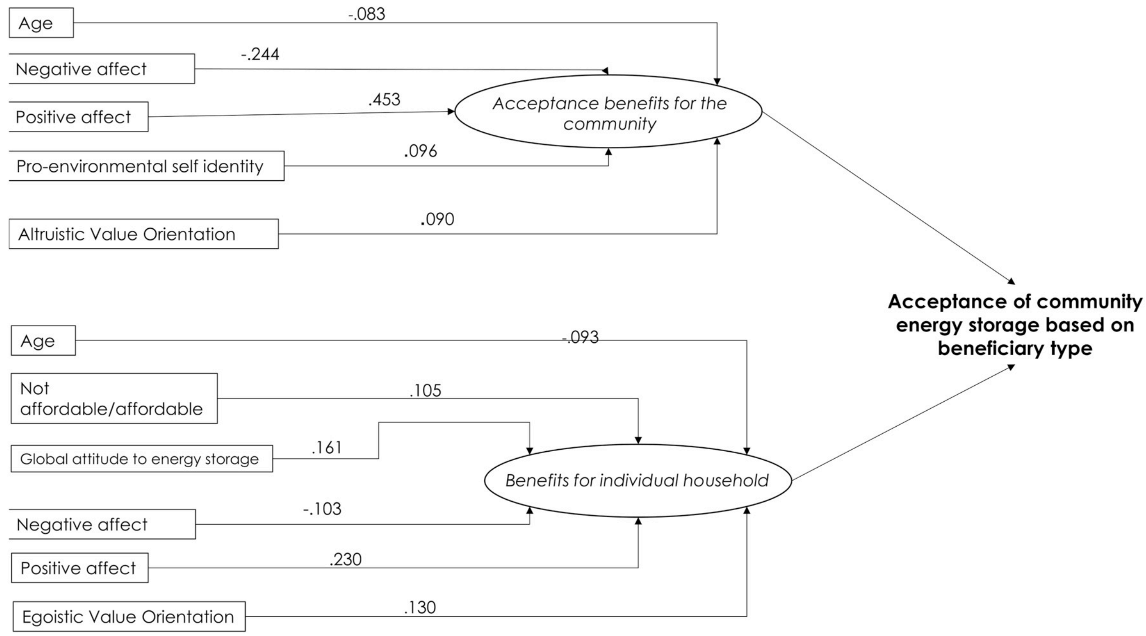

Fig. 9. Acceptance of community energy storage based on beneficiary type.

In the third case, when energy companies are the institution in charge of promotion, significant predictors are positive affect (positively) and negative affect (negatively). Model 2 and Model 3 accounted for 38% and 39% of the variance, respectively (difference not significant at $p < .05$). Including perceived benefits, costs and expectations of the technology, global attitude, and affect towards CES (model 2) increased the predictive capacity to 35.5%, significant at $p < .05$. However, this difference in the predictive capacity between model 2 and 3 was not significant at $p < .05$. Fig. 10 illustrates the significant predictors to acceptance of CES based on institution involved in the promotion.

Finally, acceptance was addressed through support for having a battery system installed in your area/community based on ownership (Table C18 appendix C): i) a private company, ii) local authority, iii) private company and the community. In the first case, Model 2 accounted for 26.3% of variance explained, increasing the predictive capacity of the model by 23.1% relative to model 1 (which includes only sociodemographic variables). Model 3 accounted for 32.9% of the variance, and in each case, the differences in variance explained are significant at $p < .05$.

Age is a significant negative predictor when only sociodemographic variables are regressed (model 1). For Model 3, positive predictors are egoistic value orientation, trust in the industry, positive affect towards CES, perceived costs being affordable or not affordable and gender. On the contrary, negative predictors are higher educational level completed, perceived benefits/expectation –making my life easier-, negative affect towards CES and altruistic value orientation.

Ownership by local authorities is negatively predicted by age and negative affect and positively predicted by perceived benefits/expectations –making life easier- and positive affect. Model 2 explained 30.4% of variance, and model 3 accounts for 32.5% of the total variance explained; the difference in variance explained is not significant at $p < .05$ between model 2 and 3, however, it is significant moving from

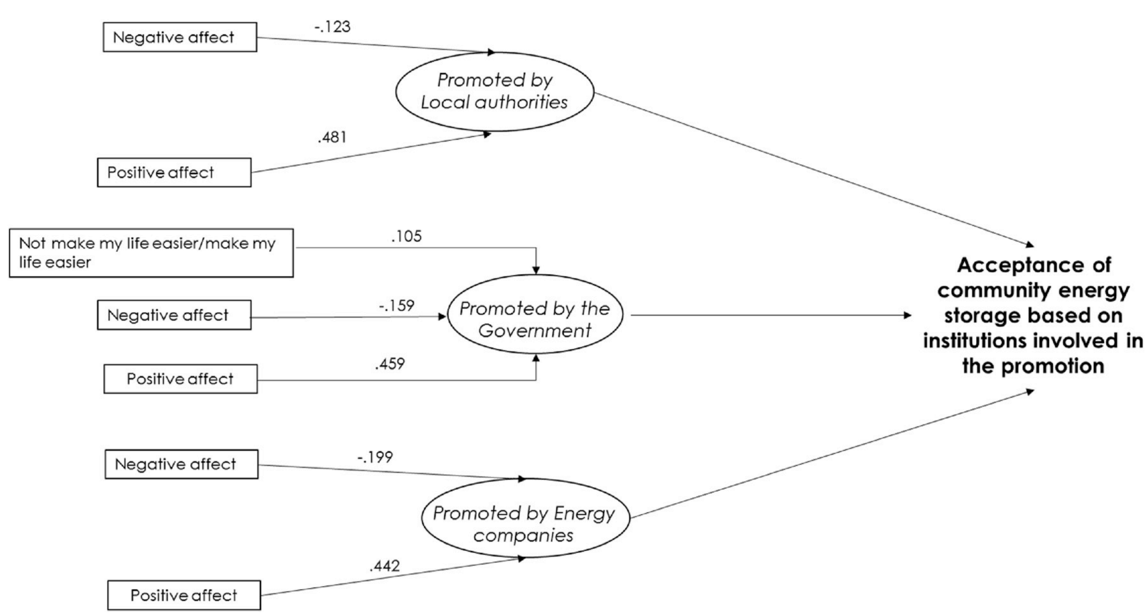

Fig. 10. Acceptance of community energy storage based on the institution involved in the promotion.

model 1 to 2 ($p < .0001$, with an increase in the predictive capacity of the model by 25.3%).

As for the other cases, age is a negative predictor when only sociodemographic variables are regressed into the model. When all variables are included into the model, negative predictors are age, negative affect to CES, positive predictors are perceived benefits/expectations –make my life easier- and positive affect towards CES.

Finally, when ownership involves both private companies and the community, the total variance explained by model 2 is 36.6%, increasing the predictive capacity of model 1 by 35%. This change is significant at $p < .001$. Model 3 accounted for 40.5% of the total variance explained, with the difference in variance between 2 and 3 being significant at $p < .05$. (Appended Table C18).

In terms of predictors (Fig. 11), age negatively predicts acceptance of CES in cases where the ownership is shared between the private company and the community in model 1. However, it loses its predictive power when all variables are included (model 2 and 3), and highest education level completed is the sociodemographic predictor for this model (negatively). As recurrent in this analysis, negative affect is a negative predictor. This option is positively predicted by positive affect, trust in the industry and egoistic value orientation.

5. Discussion

The present study has focused specifically on the influence of causal variables in explaining the acceptance of energy storage and DES technologies. The purpose was to explore the significance of the impact of these variables rather than to build a structured model of acceptance for each case (energy storage for community and household level). Therefore, first, we discuss the elements describing the actors involved in the acceptance and uptake of the technologies (i.e. attitudinal variables, sociodemographic elements). Second, we elaborate on general aspects of the deployment of energy storage technologies such as trusted actors, involved institutions, etc.

5.1. Age, values, attitudes and affect in acceptance of battery storage

In terms of sociodemographic variables, only age is a significant predictor of acceptance: younger cohorts have a more positive attitude towards battery storage, and the likelihood of installing a battery system at home is higher among younger participants. This is consistent with younger generations being more open to new energy-related products (Accenture, 2016), particularly if individuals are taking a product-oriented view of household battery storage, i.e. viewing it in part as a consumer appliance (as suggested by Taylor et al., 2013). It might be further inferred from this that there would be positive potential in exploring new business models and modes of customer engagement with younger home-owners or residents in particular.

Relatively less significant in the context of household batteries is the effect of value orientations and other attitudinal variables like trust, pro-environmental self-identity, or involvement with technological issues. Pro-environmental self-identity and altruistic value orientation are only influential in the context of CES, specifically regarding preference for the type of beneficiary. Similarly, an egoistic value orientation significantly predicts acceptance of CES if benefits go to individual households. Moreover, private ownership of CES is positively associated with a higher egoistic value orientation and high levels of trust in the industry.

The study shows that energy storage in general, but also at household and community level, remains an unknown topic for the lay-public. The level of awareness of DES is still very low, but this is recurrent in other cases for other novel energy technologies (Achterberg et al., 2010; Bögel et al., 2018; Upham and Roberts, 2011). Nonetheless, participants report a positive global attitude towards battery storage at both levels after information about the technology is provided. While it can be inferred that information provision is thus important in increasing awareness, the findings on which actors to give the information to and for which particular purposes also need to be borne in mind, considering, for example, their value orientation.

The potential role of information provision is also highlighted by the relatively high percentages of undecided and neutral responses. People reported a neutral position on whether they would vote in favour or against having a battery system at the end of the street (38.3% of participants, Fig. 2) and whether they could imagine having a battery at the end of their street, about the need of having a battery and whether having a battery would be beneficial for the community at all. On average, the percentage of undecided responses for these statements was 40% (Table C1 to Table C/Fig. 2). Nevertheless, half of the respondents consider that it could be beneficial for the community to have a battery

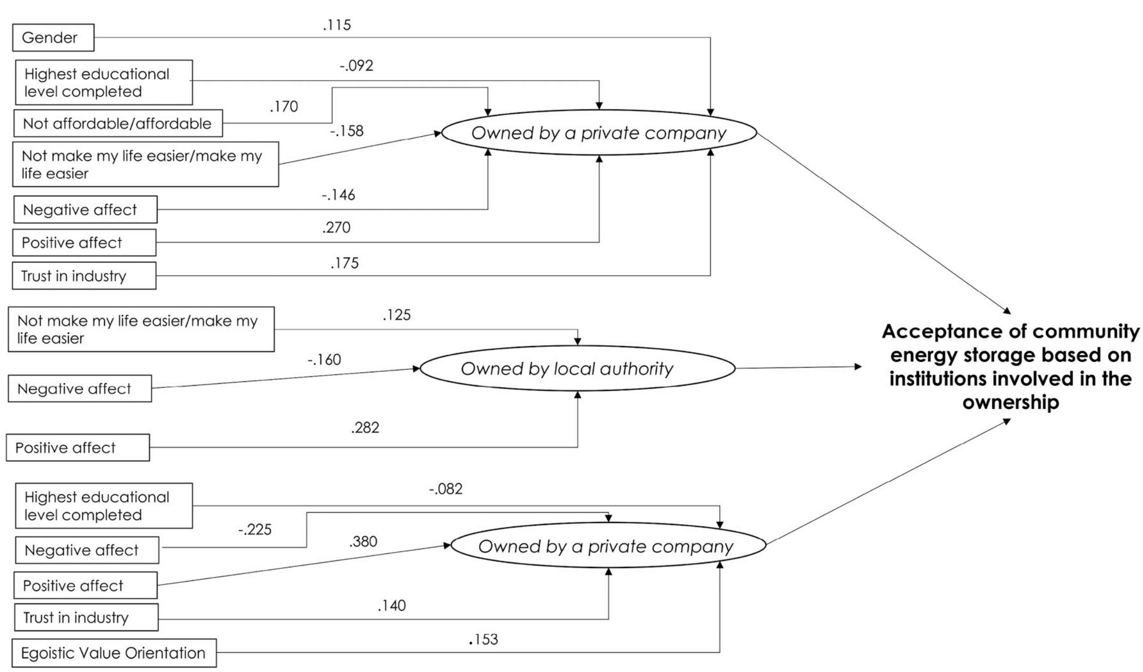

Fig. 11. Acceptance of community energy storage based on institutions involved in the ownership.

installed and they find that the area where they live could be suitable for having a battery at the end of the street.

Negative attitudes negatively correlate with the willingness to install a battery system at home. The likelihood of installing a domestic battery system is shaped by a favourable global attitude towards energy storage as a whole, interest and hope, and the level of worry and aversion to the technology. Hence affective dimensions are influential in public perceptions of energy storage, also a finding in other studies of public attitudes towards energy storage (Jones et al., 2018). In the case of CES, preferences for accepting these initiatives are also affectively influenced, regardless of the institution envisaged as in charge of promotion (local authorities, government or energy companies). Affect also determined the acceptance of CES initiatives based on where the benefits would be delivered, both for individual household and in the form of community projects.

The survey included questions on various types of expectations, which are treated here as beliefs. These types include normative beliefs about the roles of other actors such as public authorities, and also consequence-related expectations. Expectations feature in the innovation systems literature, but this is usually about actors other than users or citizens: expectations are held to influence investment-related actions and decisions (Bakker and Budde, 2012; Berkhout, 2006). If high expectations are not fulfilled, this can also damage the prospects of new technology (Alkemade and Suurs, 2012), potentially influencing not only researchers, practitioners and industry developers (Fenn and Raskino, 2008), but also potential adopters. Hence the importance of instilling realistic expectations, minimising hype and disappointment cycles (Alkemade and Suurs, 2012; Fenn and Raskino, 2008).

Participants here seem to have formed clear expectations of the technology based on the information provided. Despite the existence of neutral responses as seen in Fig. 1 (31% of participants have neutral expectations about the technology and being environmentally friendly), expectations of being affordable and of being environmentally friendly were positively associated with the likelihood of installing a battery at home and with the willingness to invest in a battery system for domestic use as shown in the regression analysis.

Based on the information provided, people generally expect energy storage to have environmental benefits, despite being informed about the life cycle environmental impacts of battery materials (Pehlken et al., 2017), including those of lithium mining on local (arid) communities worldwide (Agusdinata et al., 2018). EU regulations require the makers of batteries to finance the costs of collecting, treating and recycling all installed batteries. However, this does not necessarily equate to making used battery collection straightforward for users. Recycling of lithium is not in itself mandatory, and in the UK most of the current lithium used is either dumped in landfill or is incinerated. The respondents were informed of this but still around 32% of respondents made the judgement that domestic and neighbourhood scale batteries would be environmentally beneficial.

As reported from the descriptive analysis, expectations were also related to the technology being affordable for participants' budget and would make life easier (Fig. 2). The respondents answered thus, despite being told that the UK government has no specific funding scheme for batteries, indicating expectations of a change in future affordability through some means. The respondents were also told that battery systems are intended to minimise issues of an intermittent power supply associated with higher use of renewable energy, and this is consistent with their expectation of batteries 'making life easier'. In general, it is important not to raise false expectations of any technology.

5.2. *Trusted actors, investment and delivery of benefits in acceptance of battery storage*

The respondents expressed no clear preference for who should deliver energy storage (battery-based) initiatives, as reported by the descriptive analysis. Nonetheless, at the community level, although there was an important percentage of ambivalent responses regarding whether the local authorities and government should be in charge of promotion, there was a clear tendency of preferring them to be involved. In terms of ownership, the preferences are for public institutions (Figs. 3 and 6). More opposition and undecided respondents were found for the question of whether ownership should be only in the hands of a private company. When observing what is determining this preference we see that it is by affect towards the technology and perceived benefits and expectations about it (whether it would make life easier).

The above suggests that people expect active involvement from public authorities. This involvement is expected as well in terms of funding and paying for battery systems. Around 14% of people are willing to pay for a total cost of the battery system and around half of the survey respondents consider that public funding should be used to pay for the purchase price of the technology. The same occurs in the case of CES, where respondents consider that public funding should be used to subside these arrangements and that local authorities should promote the installation of the CES initiatives.

In a scenario of domestic storage exclusively benefitting the NG, high percentages of people are undecided and unwilling to invest. However, when the benefits are for both the NG and individuals, participants would be in general more willing to invest. People are also more willing to support CES in their locality if the benefits delivered are for their community as a whole. In contrast, if the benefits are for households exclusively, the percentage of undecided respondents is higher, and a quarter of them would not be willing to support these initiatives. These findings are consistent with previous work on community energy projects (Sauter and Watson, 2007). In general, the acceptance of projects is higher if the potential benefits for the community are clear (Wolsink, 2012).

6. Conclusions and policy implications

Effective deployment of DES technologies depends to a high degree on public acceptance. Accordingly, this study explores a range of factors that may plausibly influence the acceptance of battery storage at the household level and community level, with a nationally representative UK sample. The study finds that there is still a low level of awareness and familiarity with the idea of energy storage among the UK public. Participants nonetheless view the idea positively and have a positive feeling towards batteries in particular, in terms of hope and interest. These positive emotions and attitudes are shown to be strong determinants of acceptance and likely installation of DES technologies. Financial cost is perceived as a significant limiting barrier to battery installation at the household level, and respondents believe that public funding should be used to subsidise the purchase price of household battery systems. In terms of benefits, participants expressed a willingness to invest in a battery system if their household benefits financially. The results also indicate a clear need for the involvement of public authorities, in order to increase consumer trust in DES schemes.

From these results we can draw several policy recommendations. First, it is clear that there is a need to raise public awareness of DES, including the roles these technologies may play in the future energy system and the benefits they may bring to users. Both national and local governments, as well as technology suppliers and energy companies, could play a part in this. Encouraging different actors (not just those in the private sector) to deliver this information would be more likely to garner trust from the public.

Second, policy attention must be paid to the number of barriers that need to be overcome for energy storage to be *profitable* for users (Bale et al., 2018). Currently, most battery energy storage systems are installed alongside solar panels to maximise self-consumption of the PV generated electricity and minimise the use of more expensive electricity from the grid. Yet this is often not beneficial from a purely financial viewpoint due to the initial capital cost and lifetime of the batteries (Bruch and Müller, 2014; Ramirez Camargo et al., 2018; Uddin et al., 2017; Zhang et al., 2018). Rather than simply offering a capital subsidy for battery systems, one option would be to enable usersto access the full value of DES through selling "ancillary" services that support the operation of the transmission and distribution system to the market (Sidhu et al., 2018). These markets could be worth more than three-times those from arbitrage alone (Teng et al., 2017). New business models that capture these additional benefits are starting to emerge through the use of aggregators (Burlinson and Giulietti, 2018), but further action is needed by the Government and the regulator. The Smart Systems and Flexibility Plan (BEIS, 2017) identifies a number of measures to remove barriers facing independent aggregators, but for this market to flourish further action is needed by the regulator to clarify the rules around contracting with domestic users, and ensuring suitable consumer protection is in place.

The third area for policy action is in encouraging the role for local actors (both local authorities and community energy groups) to support community storage schemes (as opposed to those at the individual household level). Expectations of the technology and the actors involved in the deployment were clear, with the role of local authorities seen to be particularly important. Participants would be more supportive of having a community-level battery at the end of their street if it was owned and managed by the local authority rather than by a private company or a private company together with the community. Local authorities play a critical role in supporting community energy initiatives, and opportunities for DES are no different, requiring either direct involvement or support to a community-led project (Kumar, 2019) (Participants would also be more inclined to have a battery system installed in their area if the benefits flowed to local projects within the community. Community energy initiatives often involve local and/or regional governments as active partners in some respect (van der Schoor and Scholtens, 2015) and DES is likely to be no exception. The present findings are consistent with recommendations that local involvement and planning are crucial for successful implementation of new renewables energy systems (Krog and Sperling, 2019). Therefore, there is work to be done on how to engage local authorities and local communities to achieve a decentralised energy scenario that involved storage options (van der Schoor and Scholtens, 2015). In addition, more work is certainly warranted on the different policy and regulatory arrangements needed for community-owned storage business models to thrive. For wider acceptance it will be necessary to ensure that the benefits are accrued to the local area as much, if not more than, to the wider grid and national objectives.

Overall, the study confirms the key premises of technology acceptance models that essentially build on the theory of planned behaviour – namely that people are more likely to act in ways that they perceive as achievable and likely to have outcomes regarded as positive by themselves and others. In light of this, discounting the importance of public knowledge and views of energy storage would be a mistake: the study shows that neutral, realistic information is compatible with generating positive attitudes, emotions (affect) and interest. Indeed it is important to emphasise the role of affect as well as information, as positive feelings can lead to or support positive environmental attitudes.

The study revealed several challenges for the acceptance and deployment of DES at community and household level, but it also identified potential opportunities. The challenge that this poses is now for public institutions and industry to build on the social and environmental potential of energy storage, in order to support a transition to an energy system that meets the national net zero target.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2019.111194.

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