Energy Policy 133 (2019) 110908

Contents lists available at ScienceDirect

Energy Policy

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

# Deliberating the social acceptability of energy storage in the UK

Gareth Thomas*, Christina Demski, Nick Pidgeon

*Understanding Risk Group, School of Psychology, Cardiff University, 70 Park Place, Cardiff, CF10 3AT, UK*

ARTICLE INFO

*Keywords:*
Public perceptions
Public attitudes
Energy storage
Flexibility
Deliberative research
Energy system governance

ABSTRACT

Energy storage technologies are receiving increasing attention in the UK and around the world as a means of increasing penetration of inflexible low-carbon electricity generation and optimising investment in energy infrastructure required to meet international decarbonisation goals. Research into the social acceptability of energy infrastructure has compellingly illustrated the importance of societal perceptions in the successful deployment of new infrastructure. However to date, no study has empirically examined public perceptions across the broad range of storage technologies available. We address this gap by presenting qualitative findings from four deliberative workshops held with members of the British public. We show that citizens underestimate the challenge of growing volumes of inflexible low-carbon electricity generation, and respond to storage technologies through reference to commonly perceived risks and benefits. When participants discussed how storage might be funded and managed, additional evaluative criteria emerged centred around equity, vulnerability, independence and convenience. Our findings suggest that perceptions of storage technologies tend to be ambivalent, and that acceptance is likely to be contingent on whether storage technologies can be designed, regulated and governed in ways which reduce technical concerns over safety, environmental impacts and reliability, while meeting societal desires for equity and the protection of vulnerable groups.

## 1. Introduction

In future energy systems characterised by increasing electrification, intermittent or inflexible low-carbon electricity generation, energy storage is increasingly being recognised alongside interconnection, network upgrades and demand response as a promising option for matching variable supplies with consumer demand, regulating frequency and voltage fluctuation and optimising utilisation of generating capacity (HM Government, 2011; IEA-RETD, 2016; IEA, 2014; Zeyringer et al., 2018; Energy Research Partnership, 2011; Wright, 2018). Worldwide, total installed capacity of grid connected energy storage was 140 GW in 2011, almost exclusively comprising pumped-hydro electric systems. The IEA (IEA, 2014) estimates an additional 310 GW will be needed by 2050 in order to integrate new low-carbon electricity generation at a rate consistent with keeping global average temperature rises below 2 °C. In the UK, it has been projected that storage could help reduce total energy system costs by between £2 billion and £7 billion by 2030 by assisting the integration of lower cost renewable technologies and improving utilisation of other network assets (Carbon Trust & Imperial College., 2016). As of 2016, the UK was home to 3.3 GW of storage capacity of which the bulk was pumped-hydroelectric, with planning permission granted for a further 5.4 GW of capacity, including 4.8 GW for new battery storage (Gregory, 2018).

Storage technologies are heterogeneous and may be deployed on electricity transmission and distribution grids or in homes for ‘behind the meter’ electricity and thermal applications (IEA, 2014; Carbon Trust & Imperial College., 2016; Taylor et al., 2012; Eames et al., 2014). Not only does storage imply shifts in the distribution of hardware on energy networks, it may also entail citizens adopting new roles by: hosting storage in their homes and communities; adjusting their energy demand in response to time-of-use pricing; becoming active prosumers or nodes in peer-to-peer or aggregated energy networks; or as customers of novel private or municipally run energy service companies (IEA-RETD, 2016; Taylor et al., 2012; Morstyn et al., 2018; Gissey et al., 2016; HM Government & Ofgem, 2017; Sandys et al., 2017). Citizens are also deeply implicated in energy system development as voters, taxpayers and members of civil society groups who may support or oppose specific technologies, funding and regulatory mechanisms (Walker and Cass, 2007). As such social acceptability will be a key condition for enabling the smooth and timely roll out of storage technologies, both in the UK and around the world (Devine-Wright et al., 2017).

* Corresponding author.
*E-mail address:* thomasg39@cardiff.ac.uk (G. Thomas).

https://doi.org/10.1016/j.enpol.2019.110908
Received 22 August 2018; Received in revised form 24 July 2019; Accepted 28 July 2019

## 2. Background: social acceptability, technologies and governance

While there is no single definition of acceptability, the conceptualisation we use here is social in nature. Acceptability is not merely the product of individual knowledge and perception of a technological object but is shaped by the social relations, shared meanings and value systems in which technological artefacts are, or may become embedded (Wolsink, 2018). In this view, while the attitudes, knowledge and perceptions about a technology's potential risks and benefits are of interest in shaping how it may be received, these ideas cannot be divorced from the wider social context into which that technology will be deployed (Cohen et al., 2014; Evensen et al., 2018; Demski et al., 2015). Thus, while perceived risks and benefits may form part of social acceptability, studies of energy infrastructure often suggest a wider range of factors at work. Looking to the acceptability of electricity generation portfolios in Germany, Scheer, et al. (2017) identify seven evaluation categories which fuse individualised impacts with wider societal concerns; trust, national economies, consumer economics, local impacts, technical feasibility, environmental impact, health impact, social and ethical impact and catastrophe potential. Similarly Demski et al. (2015) identify six value clusters as shaping acceptability centred upon; autonomy and power, efficiency and wastefulness, environment and nature, processes and change, security and stability, social justice and fairness. While these two sets of evaluative criteria or values only map onto one another imperfectly, they share a common understanding of acceptability as deriving from both the characteristics of specific technologies, and wider sets of relationships and discourses through which they come to be perceived.

Examining storage specifically, Ambrosio-Albalá et al. (2019) suggest existing consumption; costs; family expectations; previous experiences with energy projects and municipal authorities combine with technology expectations to shape willingness to participate in household and community battery initiatives. Here and in other studies of community responses to energy infrastructure, including the smart technologies on which many forms of storage may depend (Goulden et al., 2014; Smale et al., 2017), issues relating to who controls and benefits from energy infrastructure has been shown to be a key factor in enthusiasm for different models of smart enabled demand side flexibility, and in shaping community acceptance of other energy infrastructure developments (Ambrosio-Albalá et al., 2019; Cowell et al., 2012; Rogers et al., 2008; Cass et al., 2010). Notwithstanding these insights, the few studies that have been undertaken into the social acceptability of energy storage have only examined the individual technologies in specific applications (Ambrosio-Albalá et al., 2019; Sherry-Brennan et al., 2010; Egbue and Long, 2012). To date no study has sought to empirically examine how citizens may perceive storage, at scale across the broad spread of technology and governance options available.

The case that public perceptions research into novel technologies is a necessity has been extensively made elsewhere, but to summarise there are compelling normative arguments that in a democracy members of society should have a say in the development, deployment and governance of technologies affecting their lives (Pidgeon, 1998; Stirling, 2008). Alongside these, there are also instrumental and substantive reasons why increased knowledge of social acceptability is important for taking forward key energy storage developments. Over recent decades we have seen lack of acceptability leading to resistance delay and cancellation of energy projects in the UK and other countries across Europe and the United States, including over $CO_2$ capture and storage, nuclear, wind and waste-to energy generation (Cowell et al., 2012; Davies, 2007; Feenstra et al., 2010; Oltra et al., 2012). Evidence of citizens' ability and willingness to participate in pro-environmental behaviours, including those linked to smart demand-response technologies upon which some forms of storage depend also remains mixed (Apt and Fischhoff, 2006; Fell et al., 2014; Mander et al., 2015). As Apt and Fischhoff (2006) succinctly put it:

> "Without public acceptance, it may be impossible for electric sector innovations to gain regulatory approval, find sites, or secure funding on terms allowing economic viability. Too often, though, the public face of new technologies is an afterthought."

If we are to avoid social acceptance becoming an afterthought in the case of storage, detailed research is required across the broad range of storage technologies available to investigate not only how individual technologies may be perceived both on their own terms and the risks and benefits they may offer, but also in the context of the wider social concerns and governance arrangements through which they might be delivered.

In the following, we thus aim to elucidate the range of concerns and ideas that are likely to shape societal responses to energy storage and to examine how these play out in response to specific technologies and models for governing their introduction and operation. We conducted four deliberative workshops in England, Wales and Scotland (n = 11 to 12 per group) with participants recruited to reflect a diverse range of backgrounds and perspectives. The first part of this paper explores participants' initial ideas about the UK energy system, characterising intermittency, renewable curtailment and the attendant need for storage as unfamiliar problems lacking in salience. In part two we discuss a range of risks and benefits that participants articulated in responses to stimulus materials detailing a range of storage technologies, operating at different scales within the energy system. Moving beyond risks and benefits we then examine how perceptions of storage were also shaped by the socio-technical relationships and systems in which they may be embedded. Responding to information detailing six archetypal models for governing storage within future energy systems, participants expressed a range of desires and concerns rooted in discourses relating to fairness, independence and convenience, which reflected a range of potential orientations towards storage at different scales.

While we draw on the acceptability literature in outlining our study design, in particular the decision to focus both on technologies and models for governing storage, our purpose in this article is not to synthesize or add additional evaluative criteria to any one theory or framework for thinking about social acceptability. Rather our analysis draws broadly from literatures on social acceptability, risk and technology perception (Demski et al., 2015; Scheer et al., 2017; Pidgeon, 1998; Slovic, 2010; Devine-Wright et al., 2010) in order to make sense of the citizen responses to storage we encountered in our research, and to examine how issues of acceptability play out specifically in relation to storage technologies and governance. In so doing, we argue that no single technology or governance option is likely to prove acceptable or unacceptable across society, but that responses to storage technologies and systems for governing them are likely to be better characterised as ambivalent and conditional. We argue that policy makers will need to anticipate societal concerns and conditions, in particular as they relate to the health and environmental impacts of novel storage technologies, and more significantly, justice concerns rooted in societal shifts towards more flexible energy systems.

## 3. Study design: deliberative workshops

In order to develop our understanding of the acceptability of energy storage, our research aimed to identify key criteria through which members of society interpreted and evaluated potential storage technologies and systems of governance through which their introduction, operation and relationship to society may be managed. Asking citizens directly about their views is one important means of researching public perceptions (Henwood et al., 2016). However in instances where public knowledge of technologies is low, self-report methods such as questionnaires and structured interviewing risks eliciting 'pseudo-opinions', responses lacking in clarity and conviction which prove highly unstable and subject to change when exposed to additional information (Malone et al., 2010). Nevertheless it has been demonstrated that under supportive conditions, lay citizens are capable of constructing detailed and nuanced responses to unfamiliar and complex issues in relatively short periods of time. Deliberative workshops, in which small groups convene to learn about and discuss an issue, have been particularly effective in eliciting critical reflection on the ethical, social and technological implications of a broad range of technologies (Pidgeon et al., 2014; Macnaghten et al., 2017; Carr et al., 2013).

Deliberative work aims to provide a space to open-up highly technical issues to a broader range of social and ethical concerns. This is achieved through the provision of balanced technical information and other stimulus materials designed to describe new technologies and contextualise them within ongoing and future processes of social and technological change (Pidgeon et al., 2017). This focus makes deliberative research ideally suited to examining multiple potential storage technologies operating at various scales, each carrying different implications for members of the public as citizens, consumers and users of energy storage technologies and services. Four deliberative workshops were convened at three locations across the UK: Birmingham in England (x2), Abergavenny in Wales and Aberdeen in Scotland. Workshops were held in a hotel in each location, lasted approximately 7 hours each and took place between July and October 2017. Participants were paid a honorarium of £100 for their participation.

Some deliberative researchers have been critical of approaches which explicitly frame discussions around emergent technologies, arguing that doing so privileges expert visions of the future and risks closing down space for alternative, citizen led discourses which may shape the evolution of emergent technologies in unexpected ways (Krzywoszynska et al., 2018; Wynne, 2006; Chilvers et al., 2016). While we have some sympathy for this position, given the lack of empirical data on storage perceptions, we felt it important to gain an initial response to as broad a range of technical options as was practical, and this necessitated a technology centric approach in the first instance. In order to address the issue of socio-technical co-evolution, the second half of the workshops introduced a range of potential governance frameworks and scenarios for managingstorage. Developed from pre-existing backcasting studies designed to imagine how a more flexible energy system might plausibly emerge (Taylor et al., 2012), these materials provided options for varying degrees of citizen engagement with storage and sought to broaden the focus of discussion to how interactions between citizens and the energy system may evolve in the future. While we do not claim such exercises overrode the prior technology-led framing of the workshop, or enabled participants to develop their own scenarios grounded in their daily experience, we argue this compromise approach was most appropriate given the topic hand.

### 3.1. Sample and locations

To ensure participants represented a diverse range of perspectives (Pidgeon et al., 2014), recruitment was conducted topic-blind by a professional market research company tasked with recruiting people of diverse socio-economic position, age, gender and ethnicity. The resulting sample was not statistically representative of the UK population, but instead aimed to ensure inclusion of a diverse range of experiences and backgrounds (Table 1). In addition to the above demographic criteria, we also judged housing tenure and location as potentially important in shaping how impacts of different storage technologies may be perceived. To better capture these shared experiences (Macnaghten et al., 2017), we recruited the two Birmingham groups to separately include suburban homeowners and urban tenants of rented accommodation. Abergavenny represented rural residents, in an area lacking connection to the national gas grid, and thus already reliant on domestic scale energy storage in the form of oil tanks or electrically powered heat storage (storage heaters and hot water tanks). Aberdeen was selected as an area with significant past experience of energy infrastructure development in the form of an established oil and gas industry as well as more recent low carbon energy projects. Participants were mixed in terms of housing tenure and recruited from the urban centre as well as surrounding suburbs and countryside.

**Table 1**
Socio-demographic background of participants in each of the four workshops.

| Workshop | Total number | Age brackets | Male/Female | Social grade | Tenure type |
|---|---|---|---|---|---|
| Birmingham-suburbs homeowners (B1) | 11 | 30-39 = 2<br>40-49 = 4<br>50-59 = 3<br>60-69 = 2 | 5/6 | A/B = 3<br>C1 = 4<br>C2 = 3<br>D/E = 1 | Mortgage = 6<br>Own outright = 5<br>Private rented = 0<br>Social rented = 0 |
| Birmingham- city centre tenants (B2) | 12 | 18-29 = 3<br>30-39 = 3<br>40-49 = 3<br>50-59 = 2<br>60-69 = 1 | 6/6 | A/B = 3<br>C1 = 3<br>C2 = 3<br>D/E = 3 | Mortgage = 0<br>Own outright = 0<br>Private rented = 6<br>Social rented = 6 |
| Abergavenny (Abv) | 12 | 18-29 = 6<br>30-39 = 1<br>40-49 = 1<br>50-59 = 2<br>60-69 = 2 | 5/7 | A/B = 2<br>C1 = 7<br>C2 = 4<br>D/E = 0 | Mortgage = 3<br>Own outright = 7<br>Private rented = 1<br>Social rented = 1 |
| Aberdeen (Abd) | 11 | 18-29 = 2<br>30-39 = 3<br>40-49 = 3<br>50-59 = 1<br>60-69 = 1<br>70+ = 1 | 5/6 | A/B = 2<br>C1 = 4<br>C2 = 3<br>D/E = 2 | Mortgage = 3<br>Own outright = 4<br>Private rented = 2<br>Social rented = 2 |
| **Total** | 46 | 18-29 = 11<br>30-39 = 9<br>40-49 = 8<br>50-59 = 8<br>60-69 = 6<br>70+ = 1 | 21/25 | A/B = 10<br>C1 = 18<br>C2 = 13<br>D/E = 6 | Mortgage = 12<br>Own outright = 16<br>Private rented = 7<br>Social rented = 9 |

### 3.2. Protocol and materials

A key concern for deliberative research is to frame technological developments in the widest possible context, allowing participants to consider and discuss numerous social and technological trajectories and develop their own criteria for evaluating new technologies and systems (Macnaghten, 2010; Bellamy et al., 2016); in this case for energy storage. To facilitate this, we developed a generic protocol (supplementary materials 1) for use across all workshops, along with a number of carefully constructed and balanced stimulus materials. These included: a drawing task designed to elicit participants initial knowledge and ideas about the energy system and the need for flexibility (supplementary materials 2); and factsheets providing information for seven storage technologies, including their risks, benefits and potential applications (supplementary data 3). Factsheets covered: batteries on the grid; compressed air energy storage (CAES); pumped hydroelectric storage (PHS); power-to-gas; batteries in homes; domestic heat storage and community heat storage. In order to keep the range of options manageable, information on ‘batteries’ was kept generic, covering the shared characteristics likely to be presented by a range of potential electrolyte chemistries. Two alternative options (peak natural gas electricity generation and interconnection) were also included to reflect the possibility of enhancing energy system flexibility without storage. While smart technologies and active demand response were considered for inclusion, given the prevalence of literature covering these technologies (Smale et al., 2017; Fell et al., 2014; Mander et al., 2015; Balta-Ozkan et al., 2013; Whitmarsh et al., 2011; Butler et al., 2013; Hansen and Hauge, 2017; Verkade and Höffken, 2017), the decision was taken to limit their inclusion to latter discussions of governance rather than introduce them as distinct technologies in the first half of the day. Given that issues relating to fairness, social justice and trust in regulators and developers have been shown to be central in shaping public acceptability (Demski et al., 2015; Scheer et al., 2017; Pidgeon, 1998), the second half of each workshop was devoted to examining such issues specifically. Six posters describing different ways of managing relationships between energy users, producers and storage technology providers were also produced (supplementary materials 4), along with three short narratives or scenarios (supplementary materials 5) illustrating how storage operating at different levels of centralisation may shape and be shaped by the household routines and community developments. Stimulus materials were introduced in stages throughout the day with the aim of gradually adding complexity and new dimensions to the deliberative process.

Materials were designed in discussion with engineers and energy systems experts with the aim of providing accurate and balanced information about energy storage to members of the public with little specialist knowledge of energy issues. This process aimed to inform participant dialogue, while maintaining space for unforeseen questions and evaluative criteria to emerge during discussions. In addition to standardised stimulus materials and protocols, discussions were carefully moderated by authors 1 and 2, both of whom are experienced deliberative researchers. We took care to avoid asking leading questions and to ensure discussions remained open to all participants and a range of potential responses to the materials presented. Where divergent issue framings were introduced by the research team, this tended to be as a question or prompt for further discussion made after participants has expressed their initial views. Care was taken during analysis to identify such instances and none of the analysis in this paper was solely reliant on responses prompted in such a way.

### 3.3. Analysis

All discussions were audio-recorded and transcribed professionally, checked against recordings to ensure accuracy, and then anonymised. All names are reported as pseudonyms. Analysis was thematic in nature and all coding was undertaken in Nvivo by the lead author. Following established guidelines in qualitative data analysis (Henwood et al., 2016), coding was undertaken in an iterative process involving multiple readings and interpretation of the dataset and constant cross comparison between themes. Initial readings of transcripts were used to develop indexical codes (Mason, 2002), signposting topics of discussion and ways of thinking about storage which were used to ease navigation of the data set. Through multiple re-readings, index codes were aggregated into themes which captured key ways in which participants interpreted and discussed individual technologies and governance options. The development of themes at this stage was informed by a back and forth movement between the data and wider literatures on social acceptability, technology and risk perception which provided a theoretical scaffolding for interpretation (Demski et al., 2015; Slovic, 2010; Devine-Wright et al., 2010). The resulting analysis was thus informed by these literatures while remaining grounded in the workshop data.

During analysis, the researchers began to notice dominant discourses emerging in relation to the risks and benefits associated with different technologies. An additional round of evaluative coding was undertaken to verify these intuitions and ensure the discourses highlighted as particularly salient were articulated strongly and consistently across participants and workshops (Scheer et al., 2017; Miles et al., 2014). Existing themes relating to technology characteristics were thus re-coded to reflect whether discussion within them represented perceived risks, benefits or ambivalence. Discussions during governance and factsheet activities were more finely balanced and as such a full evaluative coding was not undertaken, however to ensure reliability researchers were careful to ensure discourses identified as salient were articulated by multiple participants across multiple workshops and did not simply reflect the views of more vocal participants. All of the evaluative criteria identified as salient in this paper emerged in split group discussions facilitated by both moderators. In the interests of brevity, the findings below refer to criteria and discourses in a general sense, supporting quotes further illustrating how these were derived can be found in supplementary data 6 and 7.

## 4. Findings

### 4.1. Low awareness and salience of energy storage needs

Participants generally did not perceive energy system flexibility or storage as a significant issue and some assumed storage was already taking place. Reflecting the findings from other studies that citizens are often only vaguely aware of the energy infrastructures in which they are embedded (Devine-Wright et al., 2010; Fleishman et al., 2010), initial discussions and a drawing task eliciting participants' ideas about the energy system did not produce detailed responses regarding storage or the need for system flexibility (see Table 2). Few participants mentioned storage as something that might be present or necessary, however some did speculate it might already be undertaken somewhere on electricity networks, for example at substations or windfarms. As storage was explicitly mentioned in the facilitator's introductory comments, several of these responses may have formed in direct response to the workshop framing. However, two participants did possess prior knowledge of batteries in storage applications, referring to deployments at a local wind turbine, and news items about Tesla's Power Wall. A small number of other participants expressed prior knowledge of renewable intermittency and curtailment, but tended to speak about them in brief and uncertain terms. Reflecting on information provided by moderators about energy system flexibility, several participants stated these were issues they had not previously considered, or had assumed could be easily fixed.

**Table 2**
Pre-existing ideas about intermittency and electricity storage.

| Storage as already or assumed to be happening | Intermittency/curtailment not previously considered |
|---|---|
| "I don't know how the solar panels work. I thought that's what they were doing now; they were harvesting it in day time, and then that should be enough to supply your energy for the evening." Harriet (B1) | "Is that why … I mean, they've talked about using tidal power. I mean, is that why they haven't done that, because they can't store it?" Henry (B1) |
| "I've got [drawn] a wind farm storing electricity, and providing it into homes and businesses." Mike (B1) | "I think producing it [electricity] from natural sources, is the best method …. so, it's taken straight where it's going to be used. But it's obviously not a possible thing to do; I just assumed it would be." Mike (B1) |
| "Is there no actual way to store electricity, then?" Ollie (Abd) | "J: You know you said we had to pay to turn, if the wind turbines were producing too much wind and we have to then pay that company to switch them off? Why do we have to do that? Is that because they're private companies and-M: Yeah, it does seem mad doesn't it?" Jessica & Martin (B2) |
| "I was going to focus on the way I guess, like an ambiguous energy source like, it could be One Power or whatever. And, then it goes to like an energy station, it is processed and then it is stored I would guess, and then through underground cables back into like, people's houses … I remember reading somewhere about the Tesla Powerwall and … it can hold like a giggawatt or whatever, some energy … you can have it in your house." Imran (Abd) | "There needs to be some kind of PR campaign to educate people about all of this, all of these sorts of things, because, until I came here today, I didn't know a lot of this, and I'm glad I have, because now I know." Lesley (Abd) |
| "Yeah, somewhere for it to be stored until it's required … Like. a Lithium-ion battery kind of idea? I don't know a huge amount about it, so I don't want to go and say something that's not right." Lesley (Abd) | |
| "There's a couple next to us, they've got a wind turbine up on the side of the hill and it goes into the Grid and also it's stored in batteries for their use." Jack (Agv) | |

### *4.2. Perceived risks and benefits of energy storage*

Upon being exposed to information summarising different technologies for energy storage and system flexibility, risks and benefits formed a key lens through which participants developed nuanced responses. Cultural expectations, emotion, and anticipated impacts all shape the ways in which members of society perceive new technologies. When we speak about perceived risks and benefits, we are thus referring to interpretations shaped by subjective and shared experiences which do not necessarily reflect probable outcomes or even what is technically possible (Slovic, 2010; Whitmarsh et al., 2011). Thematic analysis of these discussions identified six dimensions through which participants interpreted potential risks and benefits (Scheer et al., 2017; Braun and Clarke, 2006): aesthetic and spatial impacts, efficiency, environment and sustainability, reliability, safety and technological progress. These themes were partly shaped by stimulus materials which contained information on storage applications, environmental, health and safety impacts but these merged with participants' own ideas in discussions about how storage should interact with wider environments and society. Technologies were subject to differing interpretations based on the same criteria. Sometimes competing interpretations were based on misconceptions about what a given technology might involve (for example fears that compressed air energy storage may involve injecting toxic chemicals underground). In other cases disagreement between participants reflected different evaluations of the same risk or benefit such as differing beliefs regarding the efficacy of safety regulations. Some technologies were viewed in more ambivalent terms, as appropriate for some areas but not others or offering benefits only in comparison with other options participants' deemed more risky. In other instances participants described key conditions or circumstances under which a technology may be made more acceptable. The diverse ways in which evaluative criteria were applied to individual technologies are illustrated in Table 3 and discussed further below.

In line with literatures on cultural expectations, place and landscape values which highlight the specificity of local contexts in shaping perceptions of acceptability (Scheer et al., 2017; Ambrosio-Albalá et al., 2019; Devine-Wright, 2009), concerns over **aesthetic and spatial impacts** were articulated in terms of what is appropriate to a given area. The size and potentially industrial appearance of battery containers in homes or on the grid were thus deemed inappropriate for some residential areas, although some participants suggested these impacts could be reduced through design or by situating technologies in new homes and estates built to accommodate them. Discourses concerning the amount of living space that may be taken up by domestic storage technologies were articulated at all sites, and while some homeowners and rural residents felt able to accommodate such technologies, others raised concerns that tenants and owners in smaller homes would find such changes difficult. At grid scale, storage technologies were often evaluated by the degree to which they were seen as distant from population centres. A discourse emerged around CAES and PHS in particular in which associations with air and water led to their being perceived as more compatible with nature and rural landscapes which the majority of participants agreed should be preserved. Unobtrusive siting underground was seen as a particular benefit of CAES, but this also extended to underground variants of community heat storage which was seen as preserving valuable urban space for other social activities. Indeed underground siting was proposed by participants themselves as a potential means of mitigating some of the spatial impacts of domestic scale battery and heat storage, as well as reducing risk to households from malfunctioning storage hardware.

Distinct from technical definitions in which efficiency is calculated on the basis of ratio between economic or energy inputs and the energy released by a given storage technology, participants' **perceptions of efficiency** were closer to the values associated with feasibility, consumer economics (Scheer et al., 2017) or a moralised sense of waste avoidance (Demski et al., 2015; Thomas et al., 2017) identified in the acceptability literature. Discourses relating to efficiency were thus informed by ideas about the ease and simplicity of construction and maintenance, durability and capacity to use existing, often natural, resources which were seen entailing lower costs and less material waste. Technologies deemed to offer additional benefits such as storage across seasons tended to be discussed as more flexible and hence cost-effective, as were those using abundant natural resources which were often seen as cheaper to operate and more robust. Power-to-gas and battery storage were discussed in more mixed terms, perceived as simple and intuitive by some, but also necessitating additional complexity in the case of infrastructure for synthetic natural gas and potentially costly and wasteful battery replacement and disposal practices.

Although increasing penetration of renewable energy and thus reducing $CO_2$ emissions was perceived as an important benefit of storage, participants also raised other **environment and sustainability** risk discourses that were unrelated to climate. Toxicity emerged as a

**Table 3**
Dimensions of risk and benefit associated with different storage technologies.[a]

| Key criteria | Perceived as a benefit | Ambivalent or conditional views | Perceived as a risk |
|---|---|---|---|
| Aesthetic and spatial impacts | Natural $_{\text{CAES, PHS}}$<br>Sleek appearance $_{\text{Bat(H)}}$<br>Out of the way $_{\text{P2G}}$<br>Good for larger homes $_{\text{Bat(H), H(h)}}$ | If it can be disguised or situated out of the way $_{\text{Bat(G), CAES, Bat(H), H(c)}}$<br>Appropriate for new homes/estates $_{\text{Bat(G), Bat(H)}}$<br>If it fits in with local area $_{\text{Bat(G), H(c)}}$<br>Better than alternatives $^{\text{CAES, PHS, H(c)}}$ | Inappropriate in/near residences $_{\text{Bat(H), H(h)}}$<br>Loss of living space $_{\text{Bat(G), Bat(H), H(h)}}$<br>Inappropriate on some landscapes $^{\text{Bat(G), Bat(H)}}$ |
| Efficiency | Simple/intuitive $_{\text{Bat(G), P2G, PHS, H(h)}}$<br>Long term/low maintenance $_{\text{CAES, P2G, PHS, H(c)}}$<br>Uses existing resources $_{\text{CAES, P2G, PHS, H(h), H(c), PNG, Int}}$<br>Re-uses existing infrastructure $_{\text{CAES, PNG}}$<br>Flexible $_{\text{P2G, H(c)}}$ | Dependent on cost $^{\text{CAES, P2G, PNG}}$<br>Dependent on population density $_{\text{H(c)}}$ | Short duration $^{\text{Bat(G), Bat(H)}}$<br>Low durability $_{\text{Bat(G), Bat(H)}}$<br>Needlessly complex $_{\text{P2G}}$ |
| Environment and sustainability | Reduced $CO_2$ emissions $_{\text{Bat(G), CAES, PHS, Bat(H), Int}}$<br>Enables more renewables $_{\text{Bat(G), CAES, P2G, PHS, Bat(H), H(h), H(c), Int}}$<br>Natural $_{\text{CAES, PHS}}$<br>Abundant resource $_{\text{CAES, P2G, PHS}}$ | Transitional role $_{\text{PNG}}$<br>Conditional on recycling or improvements in longevity $^{\text{Bat(G), Bat(H)}}$<br>Impacts minimal compared to alternatives $^{\text{CAES, PHS, H(c), Int}}$ | $CO_2$ emissions $_{\text{P2G, PNG}}$<br>Resource use $_{\text{Bat(G), Bat(H), PNG}}$<br>Pollutants- mining $_{\text{Bat(G), Bat(H), Int}}$<br>Pollutants- disposal $_{\text{Bat(G), Bat(H)}}$<br>Damage to underground ecosystems $_{\text{CAES, H(c)}}$ |
| Reliability | Mature technology $_{\text{PHS, H(h), H(c), PNG}}$<br>Natural as reliable $_{\text{CAES, P2G}}$<br>Centralised maintenance $_{\text{H(c)}}$ | Acceptable as back-up $_{\text{Bat(G), Bat(H), PNG, Int}}$ | Low durability/duration $_{\text{Bat(G), Bat(H), H(h)}}$<br>Sufficiency and discomfort $_{\text{H(h)}}$<br>Dependence on foreign countries $_{\text{PNG, Int}}$ |
| Safety | Natural/Safe in comparison to alternatives $_{\text{CAES, PHS}}$ | Hazards come with quality controls $_{\text{Bat(G), P2G, Bat(H)}}$<br>More acceptable underground $_{\text{Bat(G), CAES, Bat(H)}}$<br>Health and safety checks- reliable $_{\text{Bat(G), P2G, Bat(H)}}$<br>Health and safety checks- unreliable $_{\text{Bat(G), Bat(H)}}$<br>Safer than alternatives $_{\text{CAES, PHS, H(h), H(c), Int}}$ | Fire/explosion $_{\text{Bat(G), P2G, Bat(H)}}$<br>Toxicity $_{\text{Bat(G), CAES, P2G, Bat(H)}}$<br>Electromagnetic radiation $_{\text{Bat(G), Bat(H)}}$<br>Mechanical failure $_{\text{CAES, P2G, H(h), H(c)}}$<br>Vandalism $^{\text{Bat(G), P2G}}$ |
| Technological Progress | High-tech/Low carbon futures $_{\text{Bat(G), CAES, P2G, PHS, Bat(H)}}$ | Innovation can resolve other risks $_{\text{Bat(G), Bat(H), H(h)}}$<br>Building on past trajectories $_{\text{PHS, H(h), H(c), PNG}}$: | Not realistic $_{\text{Bat(G), CAES, P2G, Bat(H)}}$<br>Fails to address core problems $_{\text{P2G, PNG}}$<br>Old fashioned/backwards looking $_{\text{H(h)}}$<br>Conflict with previous policy/advice $_{\text{H(h)}}$ |

Table indicates spread of views across participants rather than salience. Subscript indicates which technologies were associated with each dimension. Bat(G) = Batteries on the grid, CAES = Compressed Air, P2G = Power-to-gas, PHS = Pumped Hydroelectric, Bat(H) = Batteries in homes, H(h) = Heat in homes, H(c) = Heat in communities, PNG = Peak natural gas, Int = Interconnection.

[a] A longer version of this table containing illustrative quotes can be found in supplementary file 6.

concern in relation to mining and disposal practices for a number of technologies, raising fears over long term impacts on human and ecosystem health which were seen as compounding other efficiency and safety concerns. Such concerns were particularly acute in the case of battery technologies but also emerged in relation to CAES and power-to-gas which were interpreted by a small number of participants as involving the use of toxic or radioactive materials which could cause damage if pipes or underground air or hydrogen stores were to leak. Other ecological impacts from the construction of damns and underground cavities for PHS and CAES proved less salient, and tended to be seen as 'one-off' events which did little to detract from discourses constructing these technologies as more natural and hence sustainable and beneficial (Corner et al., 2013; Thomas et al., 2018). In accordance with a social acceptance model of risk and technology perception, environment and sustainability concerns were articulated both in relation to instumentaly valued aspects of biodiversity and the natural resources, but also to their intrinsic value as things which ought to be protected (Demski et al., 2015; Scheer et al., 2017; Mabon and Shackley, 2015).

**Reliability** discourses emerged from concerns about the sufficiency of energy supplies to meet the demands of everyday life, and thus reflected concerns over security and feasibility identified elsewhere in the literature (Demski et al., 2015; Scheer et al., 2017; Butler et al., 2015). Domestic storage was seen as potentially problematic in this regard, particularly in discourses about heat storage, rooted in memories of earlier models of immersion tanks and storage heaters and associated experiences of discomfort and inconvenience. Large-scale technologies tended to be viewed more positively in this regard. Ideas about naturalness, centralised maintenance, and for PHS, technology maturity led to a view of these as more robust and reliable. While viewed as mechanically reliable, alternatives to storage in the form of interconnection and peak natural gas generation were viewed by some as unreliable over the long term due to concerns over imports and the reliability of potential trading partners, particularly post-Brexit.

While electromagnetic radiation, mechanical failures and vandalism were raised by individual participants in discussions, **safety** discourses only achieved widespread salience in relation to fire and toxic risks, particularly those perceived as posed by battery and power-to-gas technologies. When raised as a benefit, safety was always framed in response to these concerns. Safety was particularly salient in relation to batteries, where information sheets and participants' prior knowledge of electrical fires caused by mobile phones and other appliances led to significant concerns emerging. Scholars of risk perception have noted a propensity for some citizens to manage affective responses to novel risks by normalising them through comparisons with more mundane analogues and safety measures (Flynn et al., 2013; Parkhill et al., 2010; Pidgeon et al., 2012). Similar discourses formed an important basis upon which some participants were prepared to consider battery storage within or near homes although for others, the potential for risk mitigation in the future did little to ease concerns in the present.

Less salient than other dimensions, **technological progress** was nevertheless a recurring theme through which participants evaluated technologies as congruent with or divergent from their ideas about social change and what the future should look like (Demski et al., 2015). In the case of domestic thermal storage, synthetic natural gas variants of power-to-gas, and peak natural gas generation, participants expressed concerns that such technologies were old-fashioned and failed to address underlying environmental problems, particularly given incitements to reduce emissions and advice to upgrade bulky thermal storage systems to smaller, more efficient combination boilers. Conversely, progress discourses focussed on innovation as a force driving the improvement of older technologies to meet future challenges and resolving risks

**Table 4**
Salient evaluations of storage technologies.

| | Centralised | | | | Decentralised | | | Non-storage | |
|---|---|---|---|---|---|---|---|---|---|
| | Batteries on the Grid | CAES | Power-to-gas | PHS | Batteries in Homes | Heat in Homes | Community Heat | Peak natural gas | Inter-connection |
| Aest. and Space | – | + | n/a | + | – | +/− | 0 | n/a | n/a |
| Efficiency | – | + | +/− | + | +/− | – | + | – | + |
| Env. and Sust. | – | +/− | +/− | + | – | n/a | 0 | – | + |
| Reliability | n/a | + | n/a | + | +/− | +/− | + | 0 | -/0 |
| Safety | – | +/− | – | + | – | 0 | n/a | n/a | n/a |
| Tech. Progress | + | + | +/− | n/a | + | – | n/a | – | n/a |

+ positive evaluation, - negative evaluation, 0 ambivalence or conditionality, −/+ divergent opinions between participants.
Table indicates issue salience and therefore does not reflect full spread of perceptions relating to each technology, issues raised only briefly and not taken up in wider discussions are thus not included.

associated with other evaluative criteria such as enhancing battery safety and longevity. For the most enthusiastic participants, ideas about progress manifest in visions of a high-tech, low-carbon future exemplified by ubiquitous battery storage and the Tesla car.

While no technology emerged as wholly acceptable or unacceptable through risk-benefit discussions, some dimensions proved more salient than others in constructing positive, negative or ambivalent evaluations of each technology. These most salient discourses were identified using evaluative coding and are illustrated in Table 4.

### 4.3. Fairness, independence and convenience

As we have seen in the previous section, important as technological characteristics were, these were never discussed as wholely isolated from wider contextual factors that may come into play as technologies become integrated into wider social, environmental and ethical systems (Wolsink, 2018). In this section we aim to examine specifically discourses which emerged around the economic and governance arrangements through which storage may emerge in practice, and which can be of equal, if not greater, importance in shaping acceptability (Demski et al., 2015; Scheer et al., 2017). In discussions and activities contextualising storage as operated and governed at different scales, participants perceived additional risks and benefits driven by concerns over fairness, independence and convenience. These discourses typically emerged in response to stimulus materials emphasising different governance models for organising storage in future energy systems. Six posters and three corresponding scenario storylines were provided outlining potential models for governing energy storage at different scales: '*energy independence*' and '*virtual power plants*' (decentralised); '*local energy companies*' and '*community energy initiatives*' (community); '*traditional consumer*' and '*new routines*' (centralised) (Morstyn et al., 2018; Bell and Gill, 2018). 'New routines' covered household demand response operating in-lieu of storage, incentivised by centrally co-ordinated time-of-use pricing. Responses at this level sometimes related to individual technologies, but more typically were articulated in relation to levels of centralisation and modes of governance onto which individual technologies mapped imperfectly. Key themes in these responses are summarised in Table 5 at the end of this section.

Fairness concerns related primarily to the allocation of costs and benefits for provision of flexibility services. However, reflecting the deep and ideologically contested roots of ideas regarding social justice (Taylor-Gooby, 2012; Sovacool and Dworkin, 2015), multiple fairness discourses emerged in different, sometimes contradictory ways. Such discourses often focused on energy companies as untrustworthy organisations motivated by profit at the expense of consumers and other social and environmental objectives, a trend identified in other energy perception studies (Parkhill et al., 2013; Terwel et al., 2009). Such beliefs manifest in concerns that while decentralised and domestic storage may deliver benefits to citizens, 'vulnerable groups' may lack the capabilities required to realise these (Day et al., 2016). A strong social justice discourse emerged across groups that time-of-use tariffs or other initiatives designed to incentivise storage may impose unacceptable penalties on those citizens least able to cope with the cost or complexity of managing them.

Another salient discourse centred around issues of equity, expressing concerns that domestic and community scale storage may only benefit wealthier households and communities, leaving less well-off populations to shoulder the burden of higher peak-time energy prices and maintenance of national energy networks. Existing uneasily alongside equity-based discourses was another which equated fairness with reciprocity, arguing that adopting technologies and practices which support the energy system represent a form of good behaviour which ought to be rewarded. In this view financial rewards and convenience represent appropriate recompense for citizens who invest in

**Table 5**
Evaluative criteria for energy storage at different scales of governance.[b].

| Evaluative Criteria | Centralised | Community | De-centralised |
|---|---|---|---|
| *Fairness:* | • Vulnerable groups- meeting needs<br>• Vulnerable groups- budgeting<br>• Distrust of energy companies | • Vulnerable groups- meeting needs<br>• Equity- between areas<br>• Equity- access to decentralised storage schemes<br>• Reciprocity- rewarding local people | • Vulnerable groups- penalised<br>• Equity- access to storage<br>• Equity- time-of-use pricing imposing costs<br>• Reciprocity- profits for storage owners<br>• Reciprocity- lower bills |
| *Independence and control:* | • Distrust of energy companies<br>• Lack of control<br>• Encouraging wastefulness<br>• Energy companies as competent | • Community independence/empowerment<br>• Community agreement<br>• Municipal competence | • Independence and self-sufficiency<br>• User competence and novel models |
| *Convenience:* | • Convenient for users<br>• Reliable supplies | • Inconvenience- community schemes<br>• Convenience Local Authority involvement | • Inconvenience- demand response<br>• Convenience and automation- domestic storage<br>• Automation and control |

[b] A version of this table with illustrative quotes can be found in supplementary file 7.

storage or actively respond to time-of-use price incentives. In some small-group discussions, one fairness discourse emerged as particularly dominant, and on occasion equity and reciprocity based discourses were articulated in direct disagreements between participants, however more often two or three fairness discourses emerged in parallel within wider discussions.

A separate point of contention centred on the degree to which storage technologies might foster increased independence, giving households and communities more power and responsibility in shaping energy systems better suited to their needs. Perceptions of independence were shaped both by the characteristics of individual technologies, and by the wider governance frameworks in which they might be embedded (Walker and Cass, 2007). For instance, a salient discourse emerging around domestic batteries focused on how these might facilitate energy self-sufficiency. The capacity for batteries, and to a lesser extent other domestic and community storage technologies to enhance utilisation of locally produced energy and to deliver financial returns, both fed into a perception of storage as reducing reliance on national energy networks, and as empowering households and communities to take greater control of the energy they use. Combined with perceptions energy companies as untrustworthy and exploitative, and some municipal authorities this discourse led to a feeling among some participants that maintaining a centralised energy system equated to maintaining an undesirable status-quo that denied users a say in how it is governed, with potentially deleterious impacts on consumers and the environment. What we see in these discourses reflects both the common theme of trust in providers which has been well established in literatures on social acceptability, but also a desire on the part of some citizens for a more engaged model of 'energy citizenship' (Goulden et al., 2014; Devine-Wright, 2007) in which members of society are accorded a greater share of the responsibilities and benefits that come with energy system management.

In contrast to independence discourses, some participants expressed contentment with their existing energy suppliers and appreciated the security of supply such relationships provide. For this group, the added convenience and security provided by having 'experts' in control of energy provision was a valued service which might be threatened by shifts towards decentralisation. Such discourses typically focussed on the level of engagement required by end users in controlling and managing demand response and storage technologies. For technologies at the domestic and community scales, some participants expressed concern that householders, community groups and municipal authorities may lack the competence and desire to agree upon, operate and maintain new storage technologies safely and efficiently. This proved a key point of debate within workshops. For some, such concerns manifest as preferences for centralised storage models, positioning citizens in more traditional consumer roles, particularly if such services could be provided at an affordable price. Others drew on stimulus materials and analogies from daily life to suggest more automation, product and service leasing or municipal provision as means of organising energy storage and demand response practices so as to reduce the inconvenience, time and skills required for citizens and communities to engage with less centralised energy systems.

### 4.4. Reflections and limitations

A key finding from this study has been that given the opportunity to deliberate, members of the public are more than capable of forming nuanced ideas and perceptions about energy storage technologies. While this finding may come as little surprise to those versed in deliberative methods (Pidgeon et al., 2014; Macnaghten et al., 2017; Burns and Flegal, 2015), the application of this methodology to energy storage and associated governance mechanisms is novel in two ways. Firstly it has facilitated empirical investigation of storage technology perceptions which have hitherto only been examined through recourse to single technologies or analogous cases. Secondly in combining examination of these technologies with potential means of governing their introduction, our approach has allowed for a more holistic means of examining not only technologies but also potential pathways for their introduction.

We are however cognisant of our role in creating 'mini-publics' for the purpose of this study, and in selecting and defining the objects of their participation in the form of stimulus materials detailing particular storage technologies and governance types (Krzywoszynska et al., 2018; Chilvers et al., 2015). In so doing we sought to address a wide diversity of perspectives, both in terms of the backgrounds of our participants, and the range of technologies and governance options deliberated upon. The perceptions outlined above thus emerged from a dialogue between participants, each with their own experiences and perspectives interpreting the materials they were given. It is possible that the technology centric framing adopted during the first half of the day may have elicited responses which overemphasised technical characteristics at the expense of other values or non-technological solutions such as demand reduction. In particular the emergence of efficiency, safety, sustainability impacts as key evaluative criteria, was shaped in part by the framing of the initial factsheet task which provided information on related characteristics to stimulate discussion. However, given the high salience of these criteria and the broad range of external reference points through which participants discussed them, it seems likely these issues would still have emerged under less technical framings, albeit in less direct ways. Furthermore in discussion of governance models, discussions took a far less technology centric form, here participants engaged fully in identifying how divergent socio-technical pathways might impact on both their daily lives, and key areas of concern. Discourses emerging around equity, vulnerability and empowerment were not directly prompted in stimulus materials or by moderators, but emerged through participants own negotiation between proposed socio-technical regimes and broader social values and expectations with which they were seen to conflict or compliment.

While we are confident this approach ensured sufficient diversity to capture the perspectives likely to be salient in UK society, we may not have captured every potential response to storage that might emerge across society or in other national contexts. Nor can we state with confidence whether the discourses identified as most salient here would prove to be so at the population level. Some information and governance models highlighted in stimulus materials may never achieve such salience in wider public discourse on storage, and it is unlikely that, in practice citizens would compare options side by side in the way done in this study. Nevertheless, given the salience of the above criteria in discussions across workshops it would be prudent to anticipate their emergence in public discourse around the acceptability of any energy storage technology and associated governance model that becomes a reality. While our findings relate specifically to the UK, they are broadly consistent with the findings from international literatures on risk (Slovic, 2010) and energy technology perceptions (Scheer et al., 2017; Fleishman et al., 2010; Mayer et al., 2014). Combined with constraints on future energy system developments which are shared by many other advanced industrial societies, this leads us to suspect that at least some of the evaluative criteria identified in the UK would be relevant to citizens in other national contexts.

## 5. Conclusions and policy implications

In opting to examine energy storage pathways as socio-technical systems combining potential technologies and governance mechanisms at different levels of centralisation and requiring varying degrees of engagement among end users, this study has identified key criteria upon which public acceptability is likely to rest.

In the first instance we noted that energy system flexibility was an unfamiliar problem amongst our participants. Noting the unfamiliarity of many citizens with the need for electricity network upgrades Devine-Wright et al. (2010) have argued: "the relative invisibility of network organisations to the public, coupled with low expectations of residents' control over planning decisions heightens the risk of a public backlash". Considering the lack of trust expressed towards large energy providers and the unfamiliar nature of flexibility issues, we would suggest energy storage may run similar risks. Given that citizens will likely be expected to share some of the costs of enhancing system flexibility, we would thus recommend network operators and government begin engaging the public around the need for flexibility in order to reduce the potential for such costs to be received as a surprise foisted upon them by distant and anonymous entities. Such steps would not negate the need for more intensive engagement activities around specific storage projects in areas where bulk storage infrastructure may be deployed (Breukers et al., 2011; Ashworth et al., 2010). However in drawing attention for the need for greater flexibility a more national level engagement process may at least help prepare the ground for such activities to take place when needed.

On the issue of risks and benefits, we would caution against interpreting our findings as describing any storage technology as wholly acceptable or unacceptable. While some discourses such as benefits deriving from the perceived naturalness of air and water used in CAES and PHS, and risks stemming from battery composition and lifecycles did prove particularly salient, these discourses were contingent on a range of factors. While more 'natural' storage technologies may be perceived as beneficial in an abstract sense, communities confronted with concrete plans for development may feel differently, particularly if proposals were seen to threaten valued amenities or landscapes (Devine-Wright, 2009; van der Horst, 2007). Similarly while many participants expressed concern over environmental and safety risks associated with batteries, discourse describing potential mitigation measures such as recycling and safety certification also proved highly salient, pointing the way to regulatory pre-conditions on which future acceptability may rest. The identification of batteries with technological progress also suggests participants viewed these technologies as having a place in future energy systems. None of our findings suggest citizens would oppose future research, development and demonstration of any storage technology discussed. However, given some of the above concerns, we would suggest regulators and policy makers give serious consideration to how citizens may be given confidence in the safety, reliability and sustainability of storage technologies they may purchase or have deployed in their homes. Independent certification was one suggestion raised by participants themselves, but national and international codes and standards, industry organisations and best practice may also have a role to play. Should energy companies and local authorities be tasked with storage deployment in the future, the existence of independent certification and other codes may also help reduce concerns relating to trust, integrity and competence this study has highlighted.

By examining storage in the context of governing wider processes of energy systems change, this study has also shed light on additional values and criteria upon which the acceptance of storage may be predicated. The prominence given to fairness, and the multifaceted ways this played out displayed nuance seldom seen in policy discourse around storage which has thus far tended to be restricted to identifying community benefits, and incentivising storage and demand response via market wholesale and retail market reform (IEA-RETD, 2016; Gissey et al., 2016; HM Government & Ofgem, 2017). To the extent that such changes may equate to incentives for individual and community practices that may support storage, policy discourse is in line with much of the discourse we encountered around reciprocity or supporting responsibility. However, concerns that vulnerable groups should not be penalised by such changes were articulated in every workshop and were voiced in far greater strength. In order for the introduction of storage to be acceptable, policy makers need to find some means of socialising costs for vulnerable groups, be that through centralised storage provision, novel ownership, service or tariff structures. Such issues are beginning to be raised in some of the more reflective literature around energy system flexibility and market reform (Wright, 2018; Sandys et al., 2017). This is a development we welcome but further research is needed in order to identify those groups most at risk of vulnerability from drives towards system flexibility, and to identify suitable policy instruments to ensure their needs are adequately considered and catered for, for example by providing assistance with novel smart technologies or independent advise to help navigate novel tariff structures. Extant literatures on energy poverty and vulnerability may be useful starting points for this work (Day et al., 2016; Snell et al., 2018).

Perceptions of independence and control over processes of energy systems change also proved salient for some participants although for others, ideas relating to convenience outweighed the need for a say in or control over domestic and community energy supplies. This, combined with the mixed reactions different participants gave to specific technologies points to the highly variegated nature of storage acceptability. What is appropriate or tolerable for one group may not be for others. Characteristics such as the level of independence and control, convenience, aesthetic, and safety impacts were all salient across groups but their relative importance, as with other aspects of everyday energy use, differ across people and time according to the biographical, social and material contexts in which they are proposed and deployed (Thomas et al., 2017). Behind these variegated concerns was a sense among the participants of large energy companies as distant, unaccountable and untrustworthy. The dissatisfaction expressed towards such actors points to a desire for change, even among those participants for whom limited citizen involvement in energy generation and storage was seen as a desirable option. This finding begs the question, if not large energy retailers then who might take responsibility for the roll-out of storage and technologies to assist in demand response at household and community scales? Given the diversity of feeling we encountered among our participants, we would be wary of recommending a single solution to this question. Given concerns expressed about the competency of some communities and local authorities, there may well be a space for community, local government and private sector organisations to develop partnerships to deliver energy services in new, more flexible ways. It is not clear how such hybrid relationships may coevolve with storage and other flexibility technologies over the longer term. Given this uncertainty, we would recommend the development of fora and funding streams designed to bring together technology suppliers with distribution companies, local authorities and communities interested in developing more localised systems for energy provision and storage. Ongoing processes of market reform at both national and transnational levels should be kept open to novel organisational forms and relationships that may emerge from these fora. We would however bound this desire for experimentation with a warning that equity and vulnerability should be key criteria upon which new proposals for energy service provision are judged.

In many ways our empirical analysis has served to demonstrate that many of the core criteria or values identified in the social acceptability literature do indeed hold true for energy storage. Issues relating to trust and governance, equity and social justice, as well as safety, security and impacts on wider social and environmental systems all interact to shape perceptions of specific models of managing storage. What our analysis has achieved is in fleshing out how these criteria interact in the case of a range of specific technologies and governance options to produce responses that may best be characterised as ambivalent. Given the diversity of perspectives we have encountered we would argue that it makes little sense to speak of any one technology or governance option as acceptable or otherwise. Rather it may be prudent to think of acceptability in terms of the appropriateness of different storage options for different contexts and publics which will only be defined through a process of engagement about and participation in future energy systems (Chilvers et al., 2015). Nevertheless specific conditions relating to reliability, safety, sustainability and the protection of vulnerable groups are likely to be particularly important across contexts. In some areas, other factors relating to aesthetic and spatial impacts, equity, user or local control may be more relevant, particularly in the face of proposed storage deployments. The relative importance of each evaluative criteria is likely to vary across contexts. We hope in identifying key criteria through which our participants evaluated storage, this paper will provide a starting point for broadly based future public and stakeholder engagement activities and ethically aware policy thinking around energy system flexibility.

## Ethical review statement

Informed consent was obtained from all participants in the research, following procedures approved by the Cardiff University School of Psychology Research Ethics Committee. Participants names have been replaced with pseudonyms and no individual identifiers are reported in and phase of this research.

## Data availability

Audio and visual files from the workshop cannot be made publicly available due to participant confidentiality. However, we will consider requests to share anonymised transcripts for research purposes on a case-by-case basis after an embargo of two years. The protocol and stimulus materials used can be found in Supplementary Files 1–5 and are also stored on a permanent DOI address at: http://doi.org/10.17035/d.2018.0052852533.

## Acknowledgements

This work was supported by the UK Engineering and Physical Research Council (EPSRC) through the Realising Energy Storage Technologies in Low-carbon Energy Systems (RESTLESS) project [grant number EP/N001893/1]. The project is part of the EPSRC Energy Superstore Hub and is associated with the UK Energy Research Centre (UKERC). We would also like to thank Paul Dodds, Giorgio Castagneto-Gissey, Jonathan Radcliffe, Seamus Garvey and colleagues from the RESTLESS team for their expert suggestions on the design and validation of scenarios and stimulus materials developed for this research.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2019.110908.

## References

Ambrosio-Albalá, P., Upham, P., Bale, C.S.E., 2019. Purely ornamental? Public perceptions of distributed energy storage in the United Kingdom. Energy Res. Soc. Sci. 48, 139–150. https://doi.org/10.1016/j.erss.2018.09.014.

Apt, J., Fischhoff, B., 2006. Power and people. Electr. J. 19, 17–25. https://doi.org/10.1016/j.tej.2006.09.008.

Ashworth, P., et al., 2010. Communication, Project Planning and Management for Carbon Capture and Storage Projects: an International Comparison.

Balta-Ozkan, N., Davidson, R., Bicket, M., Whitmarsh, L., 2013. Social barriers to the adoption of smart homes. Energy Policy 63, 363–374. https://doi.org/10.1016/j.enpol.2013.08.043.

Bell, K., Gill, S., 2018. Delivering a highly distributed electricity system: technical, regulatory and policy challenges. Energy Policy 113, 765–777. https://doi.org/10.1016/j.enpol.2017.11.039.

Bellamy, R., Chilvers, J., Vaughan, N.E., 2016. Deliberative Mapping of options for tackling climate change: citizens and specialists 'open up' appraisal of geoengineering. Public Underst. Sci. 25, 269–286. https://doi.org/10.1177/0963662514548628.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3, 77–101. https://doi.org/10.1191/1478088706qp063oa.

Breukers, S., et al., 2011. Engagement and Communication Strategies for CCS Projects: Gaps between Current and Desired Practices and Exemplary Strategies. Near CO2.

Burns, W.C.G., Flegal, J.A., 2015. Climate geoengineering and the role of public deliberation: a comment on the national academy of sciences' recommendations on public participation. Clim. Law 5, 252–294. https://doi.org/10.1163/18786561-00504006.

Butler, C., Parkhill, K., Pidgeon, N., 2013. Transforming the UK Energy System: Public Values, Attitudes and Acceptability- Deliberating Energy System Transitions in the UK.

Butler, C., Demski, C., Parkhill, K., Pidgeon, N., Spence, A., 2015. Public values for energy futures: framing, indeterminacy and policy making. Energy Policy 87, 665–672. https://doi.org/10.1016/j.enpol.2015.01.035.

Carbon Trust & Imperial College, 2016. Can Storage Help Reduce the Cost of a Future UK Electricity System? Results from a Project on Opportunities from the Deployment of Energy Storage. Carbon Trust.

Carr, W.A., et al., 2013. Public engagement on solar radiation management and why it needs to happen now. Clim. Change 121, 567–577. https://doi.org/10.1007/s10584-013-0763-y.

Cass, N., Walker, G., Devine-Wright, P., 2010. Good neighbours, public relations and bribes: the politics and perceptions of community benefit provision in renewable energy development in the UK. J. Environ. Policy Plan. 12, 255–275. https://doi.org/10.1080/1523908X.2010.509558.

Chilvers, J., Pallett, H., Hargreaves, T., 2015. Rethinking Energy Participation as Relational and Systemic: UKERC Scoping Note.

Chilvers, J., Kearnes, M., 2016. In: Chilvers, Jason, Kearnes, Matthew (Eds.), Remaking Participation: Science, Environment and Emergent Publics. Routledge.

Cohen, J.J., Reichl, J., Schmidthaler, M., 2014. Re-focussing research efforts on the public acceptance of energy infrastructure: a critical review. Energy 76, 4–9. https://doi.org/10.1016/j.energy.2013.12.056.

Corner, A., Parkhill, K., Pidgeon, N., Vaughan, N.E., 2013. Messing with nature? Exploring public perceptions of geoengineering in the UK. Glob. Environ. Chang. 23, 938–947. https://doi.org/10.1016/j.gloenvcha.2013.06.002.

Cowell, R., Bristow, G., Munday, M., 2012. Wind Energy and Justice for Disadvantaged Communities. York.

Davies, A., 2007. A wasted opportunity? Civil society and waste management in Ireland. Environ. Pol. 16, 52–72. https://doi.org/10.1080/09644010601073564.

Day, R., Walker, G., Simcock, N., 2016. Conceptualising energy use and energy poverty using a capabilities framework. Energy Policy 93, 255–264. https://doi.org/10.1016/j.enpol.2016.03.019.

Demski, C., Butler, C., Parkhill, K.A., Spence, A., Pidgeon, N.F., 2015. Public values for energy system change. Glob. Environ. Chang. Human Policy Dimens. 34, 59–69. https://doi.org/10.1016/j.gloenvcha.2015.06.014.

Devine-Wright, P., Devine-Wright, H., Sherry-Brennan, F., 2010. Visible technologies, invisible organisations: an empirical study of public beliefs about electricity supply networks. Energy Policy 38, 4127–4134. https://doi.org/10.1016/j.enpol.2010.03.039.

Devine-Wright, P., 2007. Energy Citizenship: Psychological Aspects of Evolution in Sustainable Energy Transitions. In: Murphy, J. (Ed.), Governing Technology for Sustainability. Earthscan, pp. 63–88.

Devine-Wright, P., 2009. Rethinking NIMBYism: The role of place attachment and place identity in explaining place-protective action. J. Community Appl. Soc. Psychol. 19, 426–441. https://doi.org/10.1002/casp.1004.

Devine-Wright, P., et al., 2017. A conceptual framework for understanding the social acceptance of energy infrastructure: insights from energy storage. Energy Policy 107, 27–31. https://doi.org/10.1016/j.enpol.2017.04.020.

Eames, P., Loveday, D., Haines, V., Romanos, P., 2014. The Future Role of Thermal Energy Storage in the UK Energy System: an Assessment of the Technical Feasibility and Factors Influencing Adoption- Research Report. UKERC.

Egbue, O., Long, S., 2012. Barriers to widespread adoption of electric vehicles: an analysis of consumer attitudes and perceptions. Energy Policy 48, 717–729. https://doi.org/10.1016/j.enpol.2012.06.009.

Energy Research Partnership, 2011. The Future Role for Energy Storage in the UK. Energy Research Partnership, London.

Evensen, D., Demski, C., Becker, S., Pidgeon, N., 2018. The relationship between justice and acceptance of energy transition costs in the UK. Appl. Energy 222, 451–459. https://doi.org/10.1016/j.apenergy.2018.03.165.

Feenstra, C., Mikunda, T., Brunsting, S., 2010. In: Ashworth, P. (Ed.), Communication, Project Planning and Management for Carbon Capture and Storage Projects: an International Comparison, pp. A30.

Fell, M.J., Shipworth, D., Huebner, G.M., Elwell, C.A., 2014. Exploring perceived control in domestic electricity demand-side response. Technol. Anal. Strateg. Manag. 26, 1118–1130. https://doi.org/10.1080/09537325.2014.974530.

Fleishman, L.A., de Bruin, W.B., Morgan, M.G., 2010. Informed public preferences for electricity portfolios with CCS and other low-carbon technologies. Risk Anal. 30, 1399–1410. https://doi.org/10.1111/j.1539-6924.2010.01436.x.

Flynn, R., Ricci, M., Bellaby, P., 2013. Deliberation over new hydrogen energy technologies: evidence from two Citizens' Panels in the UK. J. Risk Res. 16, 379–391. https://doi.org/10.1080/13669877.2012.743160.

Gissey, G.C., Dodds, P., Radcliffe, J., 2016. Regulatory Barriers to Energy Storage Deployment: the UK Perspective. RESTLESS.

Goulden, M., Bedwell, B., Rennick-Egglestone, S., Rodden, T., Spence, A., 2014. Smart grids, smart users? The role of the user in demand side management. Energy Res. Soc. Sci. 2, 21–29. https://doi.org/10.1016/j.erss.2014.04.008.

Gregory, S., 2018. In: Edie Newsroom.

Hansen, M., Hauge, B., 2017. Scripting, control, and privacy in domestic smart grid technologies: insights from a Danish pilot study. Energy Res. Soc. Sci. 25, 112–123. http://doi.org/10.1016/j.erss.2017.01.005.

Henwood, K.L., Pidgeon, N.F., 2016. In: Crichton, J., Candlin, C.N., S Firkins, C. (Eds.), Communicating Risk. Palgrave Macmillan, pp. 155–170.

HM Government, 2011. The Carbon Plan: Delivering Our Low Carbon Future. Department for Energy and Climate Change.

HM Government & Ofgem, 2017. Upgrading Our Energy System: Smart Systems and Flexibility Plan. BEIS, London.

IEA, 2014. Technology Roadmap: Energy Storage. Technology Roadmap: Energy Storage, IEA/OECD.

IEA-RETD, 2016. Policies for Storing Renewable Energy- A Scoping Study of Policy

Considerations for Energy Storage (RE-STORAGE). IEA Implementing Agreement for Renewable Energy Technology Deployment.
Krzywoszynska, A., et al., 2018. Opening up the participation laboratory:the cocreation of publics and futures in upstream participation. Sci. Technol. Hum. Values 43, 785–809. https://doi.org/10.1177/0162243917752865.
Mabon, L., Shackley, S., 2015. Meeting the targets or Re-imagining society? An empirical study into the ethical landscape of carbon dioxide capture and storage in Scotland. Environ. Values 24, 465–482. https://doi.org/10.3197/096327115x14345368709907.
Macnaghten, P., 2010. Researching technoscientific concerns in the making: narrative structures, public responses, and emerging nanotechnologies. Environ. Plan. 42, 23–37. https://doi.org/10.1068/a41349.
Macnaghten, P., 2017. In: Barbour, R., L Morgan, D. (Eds.), A New Era in Focus Group Research: Challenges, Innovation and Practice. Palgrave macmillan, pp. 342–365.
Malone, E.L., Dooley, J.J., Bradbury, J.A., 2010. Moving from misinformation derived from public attitude surveys on carbon dioxide capture and storage towards realistic stakeholder involvement. Int. J. Greenhouse Gas Contr. 4, 419–425. https://doi.org/10.1016/j.ijggc.2009.09.004.
Mander, S., et al., 2015. In: Losi, A., Mancarella, P., Vicino, A. (Eds.), Integration of Demand Response into the Electricity Chain: Challenges, Opportunities and Smart Grid Solutions. ISTE, pp. 215–240.
Mason, J., 2002. Qualitative Researching. Sage Publications.
Mayer, L.A., de Bruin, W.B., Morgan, M.G., 2014. Informed public choices for low-carbon electricity portfolios using a computer decision tool. Environ. Sci. Technol. 48, 3640–3648. https://doi.org/10.1021/es403473x.
Miles, M.B., Huberman, A.M., Saldana, J., 2014. Qualitative Data Analysis: A Method Sourcebook, third ed. Sage Publications.
Morstyn, T., Farrell, N., Darby, S.J., McCulloch, M.D., 2018. Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants. Nat. Energy 3, 94–101. https://doi.org/10.1038/s41560-017-0075-y.
Oltra, C., et al., 2012. Public responses to $CO_2$ storage sites: lessons from five european cases. Energy Environ. 23, 227–248.
Parkhill, K.A., Henwood, K.L., Simmons, P., Venables, D., Pidgeon, N.F., 2010. From the familiar to the extraordinary: local residents' perceptions of risk when living with nuclear power in the UK. Trans. Inst. Br. Geogr. 35, 39–58.
Parkhill, K., Demski, C., Butler, C., Spence, A., Pidgeon, N., 2013. Transforming the UK Energy System: Public Values, Attitudes and Acceptability. UKERC, London.
Pidgeon, N., 1998. Risk assessment, risk values and the social science programme: why we do need risk perception research. Reliab. Eng. Syst. Saf. 59, 5–15. https://doi.org/10.1016/S0951-8320(97)00114-2.
Pidgeon, N., et al., 2012. Exploring early public responses to geoengineering. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 370, 4176–4196. https://doi.org/10.1098/rsta.2012.0099.
Pidgeon, N., Demski, C., Butler, C., Parkhill, K., Spence, A., 2014. Creating a national citizen engagement process for energy policy. Proc. Natl. Acad. Sci. U.S.A. 111, 13606–13613. https://doi.org/10.1073/pnas.1317512111.
Pidgeon, N., Herr Harthorn, B., Satterfield, T., Demski, C., 2017. In: In: Scheufele, D., Kahan, D., Hall-Jameson, K. (Eds.), Oxford Handbook of the Science of Science Communication, vols 141–156 Oxford University Press.
Rogers, J.C., Simmons, E.A., Convery, I., Weatherall, A., 2008. Public perceptions of opportunities for community-based renewable energy projects. Energy Policy 36, 4217–4226. https://doi.org/10.1016/j.enpol.2008.07.028.
Sandys, L., Hardy, J., Green, R., 2017. Reshaping Regulation: Powering from the Future. London.
Scheer, D., Konrad, W., Wassermann, S., 2017. The good, the bad, and the ambivalent: a qualitative study of public perceptions towards energy technologies and portfolios in Germany. Energy Policy 100, 89–100. https://doi.org/10.1016/j.enpol.2016.09.061.
Sherry-Brennan, F., Devine-Wright, H., Devine-Wright, P., 2010. Public understanding of hydrogen energy: a theoretical approach. Energy Policy 38, 5311–5319. https://doi.org/10.1016/j.enpol.2009.03.037.
Slovic, P., 2010. The Feeling of Risk: New Perspectives on Risk Perception. Earthscan.
Smale, R., van Vliet, B., Spaargaren, G., 2017. When social practices meet smart grids: flexibility, grid management, and domestic consumption in The Netherlands. Energy Res. Soc. Sci. 34, 132–140. https://doi.org/10.1016/j.erss.2017.06.037.
Snell, C., Bevan, M., Wade, J., 2018. Policy Pathways to Justice in Energy Efficiency.
Sovacool, B.K., Dworkin, M.H., 2015. Energy justice: conceptual insights and practical applications. Appl. Energy 142, 435–444. https://doi.org/10.1016/j.apenergy.2015.01.002.
Stirling, A., 2008. "Opening up" and "closing down" power, participation, and pluralism in the social appraisal of technology. Sci. Technol. Hum. Values 33, 262–294.
Taylor, P., et al., 2012. Pathways for Energy Storage in the UK. Centre for Low Carbon Futures.
Terwel, B.W., Harinck, F., Ellemers, N., Daamen, D.D.L., 2009. Competence-based and integrity-based trust as predictors of acceptance of carbon dioxide capture and storage (CCS). Risk Anal. 29, 1129–1140. https://doi.org/10.1111/j.1539-6924.2009.01256.x.
Thomas, G., Groves, C., Henwood, K., Pidgeon, N., 2017. Texturing waste: attachment and identity in every-day consumption and waste practices. Environ. Values 26, 733–755. https://doi.org/10.3197/096327117X15046905490362.
Thomas, G., Pidgeon, N., Roberts, E., 2018. Ambivalence, naturalness and normality in public perceptions of carbon capture and storage in biomass, fossil energy, and industrial applications in the United Kingdom. Energy Res. Soc. Sci. 46, 1–9. https://doi.org/10.1016/j.erss.2018.06.007.
van der Horst, D., 2007. NIMBY or not? Exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies. Energy Policy 35, 2705–2714. https://doi.org/10.1016/j.enpol.2006.12.012.
Verkade, N., Höffken, J., 2017. Is the Resource Man coming home? Engaging with an energy monitoring platform to foster flexible energy consumption in The Netherlands. Energy Res. Soc. Sci. 27, 36–44. https://doi.org/10.1016/j.erss.2017.02.015.
Walker, G., Cass, N., 2007. Carbon reduction, 'the public' and renewable energy: engaging with socio-technical configurations. Area 39, 458–469. https://doi.org/10.1111/j.1475-4762.2007.00772.x.
Whitmarsh, L., et al., 2011. Public Attitudes to and Engagement with Low Carbon Energy: A Selective Review of Academic and Non-academic Literatures.
Wolsink, M., 2018. Social acceptance revisited: gaps, questionable trends, and an auspicious perspective. Energy Res. Soc. Sci. 46, 287–295. https://doi.org/10.1016/j.erss.2018.07.034.
Wright, A.C., 2018. Reform of power system governance in the context of system change. In: IET Smart Grid 1. pp. 19–23. https://doi.org/10.1049/iet-stg.2018.0040.
Wynne, B., 2006. Public engagement as a means of restoring public trust in science – hitting the notes, but missing the music? Public Health Genom. 9, 211–220.
Zeyringer, M., Price, J., Fais, B., Li, P.-H., Sharp, E., 2018. Designing low-carbon power systems for Great Britain in 2050 that are robust to the spatiotemporal and inter-annual variability of weather. Nat. Energy 3, 395–403. https://doi.org/10.1038/s41560-018-0128-x.
Taylor-Gooby, P., 2012. Equality, rights and social justice, in The Student's Companion to Social Policy (eds P Alcock, M May, & S Wright) 26-32 (Wiley-Blackwell).