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Socially smart grids? A multi-criteria mapping of diverse stakeholder perspectives on smart energy futures in the United Kingdom

Nigel Hargreaves, Tom Hargreaves *, Jason Chilvers

Science, Society and Sustainability (3S) Research Group, University of East Anglia, Norwich NR4 7TJ, UK

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ABSTRACT

Smart grids have been heralded as means to build more efficient, connected and sustainable energy systems yet they bring forward many possible futures and potential downsides. Whilst most existing analyses have been technical in focus, emerging social studies of smart grids have separately considered their imagined socio-technical futures, generalised public perceptions, or micro-scale responses in domestic and community settings. In this paper we aim to address the 'social smartness' of smart grid research by connecting these hitherto distinct strands of work through a distributed appraisal of potential future pathways for smart grid development in the United Kingdom. We involved diverse system actors ($n = 26$) ranging from experts and policy makers through to interested citizens in a multi-criteria mapping process to systematically appraise a range of sociotechnical smart grid visions. We present the core criteria that respondents developed to determine what it means for smart grids to be both technically and socially smart. These were: technical feasibility, environment, supply security, data security, governance, finance, user engagement, and equity. We show how both citizen and specialist appraisals support more distributed smart grid visions and call for solutions that democratise the energy system through inclusive forms of ownership and decision-making. We suggest that the challenge of developing smart grids in ways that are both socially and technically smart requires processes of responsible innovation to become more distributed across scales.

1. Introduction

By applying information and communication technologies (ICTs) to the electricity grid, smart grids promise to offer real time flows of information throughout the electricity network allowing more detailed control and management of both supply and demand and, in so doing, allowing more efficient system management [1,2]. The development of smart grids thus represents a major innovation in energy infrastructure that - through improved efficiency, the enhanced integration of renewables, and the potential to support demand side management - is seen by many as capable of helping solve issues as diverse as supply security, carbon dioxide emissions, peak demand, distribution and transmission losses, storage, supplier switching, fraud and inaccurate billing. Indeed, Verbong et al. [3], suggest that smart grid proponents see them as having the potential "to solve almost every thinkable energy issue" (p120).

Despite their evident potential, however, to date this has rarely been realised in practice. As Lovell notes, there is a "mismatch between planned (often aspirational) objectives [of smart grids] and the realities of implementation. In other words, how society has responded to smart grids is quite often a long way away from how those involved in smart grids thought it would at the planning stage. Overall, smart grid projects have taken longer to implement, have cost more, and have had fewer financial benefits than expected" ([4], p13). In this paper we argue that a key explanation for these failings is that society has too often been shut out of smart grid debates and developments. The vast majority of smart grid research to date has, perhaps unsurprisingly, been technical or techno-economic in focus (e.g. [5–12]) to the extent that, even today, definitions and representations of smart grids "tend not to have any people in them" ([4], p8). This is a major problem not only because failure to involve society in the design and development of future energy systems can result in delays, cost overruns and lower than expected benefits, but also because these systems will affect all people's lives and should therefore be open to deliberation by wider society and not solely to technical experts [13,14]. A working hypothesis of this study has been that the smartness (or dumbness) of smart grids will come from how they attend to social as well as technical dimensions [15] or, in other words, that a truly smart grid will necessarily be both technically as well

* Corresponding author.
E-mail addresses: Nigel@synfo.co.uk (N. Hargreaves), Tom.Hargreaves@uea.ac.uk (T. Hargreaves), Jason.Chilvers@uea.ac.uk (J. Chilvers).

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as socially smart. This study was thus motivated by the narrow ways in which 'smartness' has so far been understood as a predominantly technical issue and sought to ask new questions about and generate new understandings of what 'social smartness' might actually mean.

Drawing on a rapidly growing social science literature on smart grids, we argue that society has been excluded in at least four key ways. First, plans and visions of future smart grids have typically been technical in focus, neglecting the sociotechnical realities and contexts they must contend with [4]. Second, only a narrow range of actors - typically those with technical or economic expertise – is usually involved in the development and evaluation of smart grids to the exclusion of other stakeholders with other values and insights [16]. Third, smart grids have often been evaluated in relation only to technical or economic criteria with too little attention given to wider public or social values [17]. Fourth, the result of these exclusions is that the societal implications of different smart grid futures have too often been narrowly framed and understood [18]. Whilst recent social science research on smart grids has started to address each of these issues, this has often been done in isolation. In this paper, we aim to address the 'social smartness' of smart grid research by tackling all four exclusions in an interrelated and co-produced manner. Specifically, we: i) develop a range of socio-technical smart grid visions, ii) engage a diverse and distributed set of smart grid stakeholders in a process designed to iii) elicit relevant social values in the form of criteria, and iv) appraise each vision in relation to each criterion to systematically explore pertinent societal implications. To do this, we employ multi-criteria mapping (MCM), a method designed explicitly to open up the appraisal of different sociotechnical futures to plural and diverse visions, actors and values [19].

The next section outlines the burgeoning social science literature on smart grids focussing particularly on the different ways in which society has been envisaged and engaged in smart grid research. Section 3 details the MCM methodology and how we developed and applied it in this study. Section 4 summarises the results of the study, exploring participants' qualitative and quantitative appraisals of a range of different sociotechnical options for smart grid futures. Finally, Section 5 concludes the paper by outlining the core implications of the analysis for how smart grids might be developed in ways that better attend to key social values and concerns.

2. Societal engagement with smart grids

Whilst research in this area remains largely technical in focus, the last decade has seen an upsurge in social science research exploring the different ways society is envisaged and engaged in the emerging smart grid. Building on Skjølsvold et al. [20], we distinguish three distinct strands of work on societal engagement with smart grids that respectively explore: i) the visions and sociotechnical imaginaries of different actors, ii) public attitudes and perceptions of smart grids, and iii) user-engagement with smart grid technologies.

First, a core strand of work has explored different visions for smart grid development and the kinds of sociotechnical imaginaries [21] embedded within them. This work has examined how smart grid visions have been developed by networks of actors with particular forms of knowledge, competence and expertise and who exhibit implicit and often partial notions of what constitutes the public good [22–25]. In so doing, it has highlighted not only that smart grid visions are diverse and interpretatively flexible, constructed through negotiation between multiple, often competing actors and meaning different things to different groups, but also that these often technical visions always also include particular social visions and representations of users [26–28]. They are always produced from particular perspectives and exclude others, they pursue some development trajectories and not others, and they thus generate both winners and losers. A key finding in this body of work is that there has been a lack of public debate about smart grids that has, in part, served to generate a gap between the values embedded in state and science-led imaginaries of smart grids and those of the wider public [24,29,30]. In this paper, we seek to address this gap by engaging diverse societal actors – including specialists and citizens – in both elucidating relevant public values and using them to appraise diverse smart grid visions.

A second major strand of work has examined public attitudes to and acceptance of smart grids [31–37]. This body of work has identified a number of public concerns about smart grid technologies relating to issues such as trust, control, surveillance and privacy, data security, health and environmental concerns [5,37,38]. In relation to emerging digital energy platforms for example, Niet et al. [39] highlight public values relating to sustainability, reliability, affordability, security, privacy, balances of power, equity and equality, control over technology, and autonomy as of particular importance. Recent work within this strand has paid attention to moral and ethical concerns relating to energy justice in smart grids. This work has emphasised public concerns around inclusivity in decision-making and the need to prioritise the concerns of vulnerable groups [40–43], but has also questioned whether smart grids are suitable vehicles for addressing wider energy justice issues [44]. Whilst this body of work has done much to identify and delineate public concerns and values, these are often derived from studies and surveys designed to elicit levels of 'social acceptance' to top-down smart grid visions among highly orchestrated 'representative publics' [33,34]. What is needed, and as we seek to develop in this paper, is more attention to the visions, values and sociotechnical imaginaries of the diverse and distributed actors that will not merely respond to smart grids, but also play an active part in co-shaping them (cf. [45]).

The third major strand focusses on specific smart grid trials and pilots – often at the domestic or community scale – to explore how people actually engage with the different technical components of the smart grid in situated, everyday settings [46]. This work has explored how householders use and respond to a wide range of different smart grid components and technologies such as smart home technologies, heat pumps, solar photovoltaics, domestic batteries or electric vehicles (e.g. [47–55]); as well as how community groups are developing their own localised forms of micro-generation or engaging in community-scale smart grid development [56–58]. Recent work in this strand has focussed less on users and more on the forms of governance and policy experimentation involved in smart grid trials and pilots (e.g. [59,60]). Key findings in this research emphasise how smart grid designers and developers often fail to account for the everyday practicalities, local situatedness, and social dynamics that smart grid pilots must contend with. The result is that smart grid technologies are often not used in the ways their designers intend, that they may not be transferable from one context to another, that they may be abandoned by their users and thus fail to deliver on their potential or, worse, that they may fail to challenge and thus serve to reinforce unsustainable levels of energy demand. Whilst this body of work has vitally emphasised the often yawning gap between the imagined users of technology developers and 'real' users in actual homes and communities, it also typically remains at a micro scale, affording users the right of response to innovative new consumer technologies, but doing little to simultaneously explore their broader citizenly concerns at the scale of the whole smart grid. More work is therefore needed to explore how a wider, more distributed system of practices and decision-making may shape the future of smart grids in more socially responsive and responsible ways.

As this brief review has highlighted, despite the considerable progress made in recent years, there remains an important need to further expand and deepen societal engagement with the development of smart grids. Whilst, as outlined, recent work has variously developed diverse sociotechnical visions of smart grids, engaged with different sets of actors and elucidated relevant public values, this has rarely been done in concert. Instead, studies have tended to focus on one aspect at a time, such as developing more sociotechnical visions of smart grids [61] or elucidating relevant public values [39]. We suggest this important and valuable work does not go far enough in recognising how the actors,

Table 1
Option definitions summary.

Option		Summary definition
CO1	Government-led Strategy	A successful Government-led smart meter roll-out generates new market and service opportunities that stimulate active consumer engagement.
CO2	Commercial Engagement	A smart grid driven by increased involvement of multi-national ICT companies utilising end-user data to develop new products and services and improve grid management.
CO3	Community Energy	Communities take more control and ownership of their energy requirements, motivated by climate concerns, energy security, rising energy bills and opposition to powerful utilities.
CO4	Passive Consumers	Energy supply growth from gas and interconnectors balances intermittent large-scale renewables. Smart technologies balance the grid. No engagement required from consumers.
DO1	Smart Meter Redesign	End users given ownership of smart meter data leading to development of more advanced smart meters giving users more choice and control over smart home technologies.
DO2	Energy Democracy	Citizens heavily engaged in shaping the Governments vision for end-user engagement in the smart grid through a series of community workshops.
DO3	Energy Islands	Citizens take full control over their electricity supply through distributed generation and virtual power plants connected into end-user owned microgrids or 'energy islands'.
DO4	Conservation Alternative	End-users choose to pay towards a national programme of energy conservation and efficiency instead of the smart meter rollout and smart grid development.

Note: Core Options (CO1–CO4) were appraised by all participants and Discretionary Options (DO1–DO4) were selected for appraisal by some participants (see Table 2 and [69] for full details).

visions and values of future smart grids are not separate from one another, but rather are interrelated and co-produced across socio-technical systems (cf. [62]). Increasing the social smartness of smart grids therefore requires work that systematically examines these interconnected and co-productive relations to explore how diverse actors variously appraise and anticipate the implications of different smart grid visions in relation to different societal values.

3. Methods

This section outlines the methodological approach adopted in this study, detailing how we developed and applied the MCM method. MCM is an established multi-criteria option appraisal method capable of mapping diverse perspectives in the anticipatory appraisal of complex policy issues and emerging technologies, as successfully applied to agricultural biotechnologies [19] and climate geoengineering [63]. MCM is particularly relevant to appraising the emergent sociotechnical futures of smart grids due to its distinct emphasis on 'opening up' the framings and perspectives that permeate the issue, compared with other approaches to expert and public elicitation (such as multi-criteria decision analysis and public opinion surveys) [64].

The MCM method is based on four underlying values of: inclusion, seeking to develop more inclusive, equitable and accessible modes of appraisal and particularly including more marginalized perspectives; 'opening up', aiming to give balanced attention to exploring and illuminating contending views and uncertainty as opposed to 'closing down' around single final views; agency, trying to maximise the agency of participants in how their perspectives are represented; and, transparency, seeking to fully and clearly convey results to all parties with an interest in the debates at hand [19]. The approach is thus well-suited to our aims in this project to open up deliberation about potential smart grid futures beyond technical issues to include social and political concerns, and beyond experts and policy makers to give balanced attention to public views as well. The MCM method involves three core stages: i) producing a set of options for participants to appraise; ii) conducting MCM interviews with participants in which they create a set of criteria with which to appraise each of the options and score the relative performance of each option on each criteria; and iii) analysing both the qualitative data generated in interviews as well as the quantitative data produced through option scoring. Full details on the MCM process are available in [19] and in the MCM Manual [65]. Here we provide further information on specific aspects relevant to this study.

3.1. Framing and option development

In response to the narrow, technical focus of much prior research on smart grids, this study sought actively to open up appraisals of smart grids to include a diverse range of actors, forms of governance, and scales of operation as well as different technical options (see also [66,67]). We therefore chose to frame the study around how smart grids might be 'organised' to account for both social and technical concerns. This framing emphasised different possible configurations of social, political and technical issues in future smart grids. To develop the options we conducted a review of different smart grid and energy scenarios (e.g. [57,66,68]) to identify a wide range of technical, economic, political, environmental and social issues to explore. We sampled these scenarios for diversity in the following categories: key actors (e.g. government, energy industry, ICT industry, community); type of public engagement (e.g. passive consumers, active prosumers, community volunteers, democratic citizens); and geographical scale (e.g. interconnected cross-national energy grids, national grids, federated community-scale microgrids). This allowed us to generate a set of eight discrete options for appraisal. Four of these were considered core options to be appraised by all participants, and four were discretionary options to be appraised at the participants' discretion (see Table 1 for a summary of the options).

3.2. Sampling and recruitment of participants

A diverse sample of 26 (17 professionals and 9 interested citizens) were interviewed for the study. The 17 professional interviewees were recruited based on their appreciation of the many challenges of realising smart grids and were sampled for diversity across: 1) different sectors working on smart grids (government, private sector, academic, NGO), and 2) disciplinary or professional specialism (covering engineering and social science perspectives across energy networks, IT development, environmental sustainability and community development). Whilst we followed other MCM studies in recruiting a diverse sample of professionals [19,63], a core concern of this study was to move beyond state, science or industry-led visions and values to open up to a more symmetrical and comparative analysis that incorporated the more distributed and perhaps grounded perspectives of interested citizens (i.e. those who have some interest in engagement with energy futures, but as citizens and not in a professional capacity). Accordingly, we placed considerable emphasis on interested citizen recruitment to ensure they were well-represented in the final sample. In total 9 interested citizen interviewees participated in the study. They were recruited using a snowball sampling technique and for diversity of their levels of interest

Table 2
Participant summary.

ID	Sector	Area of expertise/ experience	Discretionary (DO) or Additional (AO) options appraised
A1	Academia	Smart ICT engineering	DO3, DO4
A2	Academia	Energy social science	DO2, DO4
A3	Academia	Electrical engineering	DO1, DO4
A4	Academia	Environmental economics	DO4, AO1
G1	Government	Future electricity networks	DO2, DO3
G2	Government	Sustainable development	DO2, DO3
G3	Government	Energy services	DO1, DO3
P1	Private sector	Wireless systems	DO2, DO3
P2	Private sector	Smart hardware & software	DO3, DO4
P3	Private sector	Smart grid applications	DO1, DO3
P4	Private sector	Future energy demand	DO1, DO3
P5	Private sector	Energy network development	DO3, DO4
P6	Private sector	Energy metering	DO2, DO4
N1	NGO	Sustainable energy	DO2, DO3
N2	NGO	Environmental campaigning	DO3, DO4
N3	NGO	Community renewables	DO1, DO3
N4	NGO	Community energy enterprise	AO2
C1	Interested citizen	ICT internet applications	DO1, DO4
C2	Interested citizen	Architecture	DO3, DO4
C3	Interested citizen	Art & education	DO2, DO4
C4	Interested citizen	Unemployed	DO2, DO4
C5	Interested citizen	Health	DO2, DO3
C6	Interested citizen	Environmental activism	DO1, DO4
C7	Interested citizen	Music	DO3, DO4
C8	Interested citizen	Finance & microgeneration	DO1, DO4
C9	Interested citizen	ICT training	DO1, DO4

and engagement with energy and sustainability issues. Critically, their interest in energy futures and smart grids was not necessarily technical, with many having no energy or engineering interest or knowledge. Rather their 'interest' in and engagement with energy futures was often environmentally or socially motivated, such as related to concerns about climate change or improving their local area or community. Prior to participating in the interviews, a preliminary phone call was conducted with all interviewees to screen them in relation to these criteria and to establish their interest in and commitment to the study. Table 2 provides summary details of all 26 participants and which of the four discretionary options they chose to appraise.

3.3. Interviews and analysis

Before conducting the interview, all participants were sent further information about the interview process and asked to prepare for the interview by reviewing a summary of all eight core and discretionary options. The interviews lasted around 2 h on average and were conducted on a one-to-one basis at the interviewee's workplace, home or a neutral location. The interviews followed the standard MCM format (see [65]). First, participants were first asked to give their general reflections on the framing of the study and the range of different options they had been sent in advance. They were then asked to select up to six options to appraise (including all four core options, and either two discretionary options or any additional options they wished to suggest). Two participants opted to create additional options of their own[1], but as these both represented a combination of the existing core and discretionary options, did not introduce any new social or technical features, and were each appraised by only a single participant, we have not included them in the subsequent analysis. Second, participants were tasked with defining and developing a set of criteria or social values with which to appraise the options. Third, they were asked to appraise each option, one-at-a-time, in relation to each criteria giving a score out of 100 for how well they think the option would perform. Here, the MCM software allows participants to record both an optimistic and pessimistic score providing an indication of uncertainty. It also produces an aggregate score for each option in relation to all criteria to provide an overall performance rank (see [70] for further details). Participants' scores were recorded in the offline MCM tool and then uploaded for quantitative analysis in the online MCM software (www.multicriteriamapping.com). Fourth, and finally, participants were shown their overall rankings of the options, and asked if they wanted to weigh any criteria differently to ensure that the quantitative results accurately matched their personal and qualitative appraisal of the different options.

The interviews were audio recorded and transcribed verbatim for qualitative analysis using NVivo.[2] Qualitative analysis followed the MCM method [65] and was based on codes relating to participants' views on the overall problem framing and options, criteria for options appraisal, the reasonings behind their scoring of each option on each criteria, and their reflections on the overall appraisal and option performance. Participants developed 141 individual appraisal criteria in the interviews, which were then assigned to criteria groups based on qualitative similarity and difference in later analysis (as presented in Table 3 below). In the results that follow, quotations are used to illustrate participants' perspectives. Unless otherwise stated, these quotes are representative of themes derived from across several interviewees.

Table 3
Summary of criteria groups.

Criteria groups	Examples of criteria developed by participants
Data security	Consumer data security; system data security; safety & privacy; trust
Environment	Environmental impact; environmental damage; environmental benefit; climate change; health; biodiversity
Equity	Fairness; inequality; energy equality; social inclusivity; affordable warmth
Finance	Cost; economic accessibility; least cost method; cost reduction; financial benefits; costs are shared; innovative business models
Governance	Energy policy; long-term planning; regulatory and market; energy policy commitment; trilemma optimisation
Supply security	Energy system security; security of supply; reliability; resilience; efficiency and quality of supply
Technical feasibility	Technical feasibility; technical reliability; technology availability; scalability; network operability
User engagement	Customer engagement; education and awareness; understandability; simplicity; ease of use; consumer empowerment

[1] Participant A4 created AO1 which they called the 'Public and Private' Option, this combined a government-led smart meter rollout (CO1) with greater user ownership and control over data (DO1). Participant N4 created a 'Reality' option which combined what they saw as the best bits of all core and discretionary options to generate a more diversified smart grid development.

[2] To preserve anonymity, and in line with the ethical consent granted by participants, we are unfortunately unable to make the interview transcripts open access.

4. Results

This section presents the results of the MCM interviews. Section 4.1 explores participants' initial responses to the options. Section 4.2 outlines the process of criteria development, showing how participants developed eight broad social values as criteria with which to appraise the options. Sections 4.3 and 4.4 show how participants appraised each core (Section 4.3) and discretionary (Section 4.4) option. These sections draw predominantly on qualitative data to examine how each option performed in relation to each criteria and introduce the key issues participants raised about each potential smart grid future. Finally, Section 4.5 draws mainly on the quantitative MCM analysis to reveal the overall option performance rankings, identify key issues from across all options, and to assess the extent to which participants from different sectors appraised and ranked the options differently.

4.1. Option exploration

All participants were asked to appraise six options in total. This was to include all four core options, up to two of the discretionary options and any additional options they wished to generate themselves.

At the outset of the interview, participants were asked to give their initial reactions to the core and discretionary options and to choose which of the discretionary options they wished to appraise. The main comments on the options as a whole were that they were perhaps focussed too heavily on electricity (A2) and could have done more to explore gas and heating more directly as this issue only appeared explicitly in the Passive Consumers option. C2 also commented that, despite our efforts to emphasise the sociotechnical organisation of smart grids, the options were "*very technologically-led…there is only one option* [Conservation Alternative] *that says you can walk away from the smart grid if you wanted to*" (C2). Despite these comments, in general participants were satisfied with the range of options presented, suggesting they were reflective of the potential diversity of issues likely to be encountered in future smart grid evolution.

In choosing which of the discretionary options to appraise, several participants (A1, A3, N1, G1, G2) noted that Conservation Alternative should not be seen as a separate option in and of itself but that it needed to be included in all options. Further, some suggested that Smart Meter Redesign would be inevitable in order to avoid existing smart meters becoming quickly obsolete (e.g. P1, P2, C7). These were offered as reasons for not appraising these options. Overall, however, each discretionary option was appraised by a minimum of nine participants and, with the exception of Conservation Alternative which was not appraised by any Government interviewees, all other options were appraised by at least one participant from each sector.

4.2. Criteria development

The second stage of the interviews involved participants developing a set of criteria with which to appraise the options. Each participant developed their own set of criteria and provided a clear and distinguishing definition of each criterion. In total 141 criteria were developed across all 26 participants. These criteria spanned across engineering, natural and social science concerns ranging from technical feasibility to fairness and inclusivity, they also covered core concerns within the energy industry such as security of supply, the IT sector such as data security and privacy, as well as more everyday concerns such as impacts on health or how users might engage with smart technologies in daily life. To aid analysis, these 141 criteria were coded into eight distinct criteria groups as shown in Table 3.

4.3. Option scoring: core options

After giving their initial reactions to the options, selecting which options to appraise and developing the criteria, the next stage of the interview involved systematically scoring each of the options in relation to each of the criteria. Fig. 1 (below) provides an overview of how each option performed on each criteria as well as their overall performance. The following sub-sections draw on the qualitative data to outline participants' rationales for and the key outcomes of this appraisal process.

4.3.1. Government-led Strategy

Government-led Strategy explored a smart grid future in which a successful state-led smart meter roll-out generates a range of new market and service opportunities that stimulate active consumer engagement. This option performed moderately overall, performing slightly better among interested citizen than professional interviewees. This was driven by strong scores for data security, environment and governance criteria and moderate scores on all other criteria groups (equity, finance, security of supply, technical feasibility and user engagement). Interviewees remarked that any future smart grid would demand strong Government leadership to overcome short termism and provide the long-term strategy necessary for infrastructure development (A3), to set standards and lead the way in the absence of voluntary action (G1) and to "*set an example*" and bring consumers along by demonstrating that "*We're all in this together*!" (C7). Whilst the option scored well for data security, this was still raised as a concern by participants from across several sectors who saw this as a somewhat unavoidable issue for almost all options: "*Data must not be intercepted by third parties – malicious or curious. If I'm having a smart meter outputting data, I don't want anyone to take it, even if I am not doing anything particularly sensitive to security concerns*" (P1). Both end user and professional interviewees also expressed considerable doubt about the likelihood of mass public engagement around energy

	Data security	Environment	Equity	Finance	Governance	Supply security	Tech feasibility	User engagement	Overall option performance
CO1: Government-led strategy	●●●	●●●	●●	●●	●●●	●●	●●	●●	●●
CO2: Commercial Engagement	●●	●●●	●●	●●	●●	●●	●●●	●●●	●●
CO3: Community Energy	●●	●●	●●●	●●	●●●	●●	●●●	●●●	●●
CO4: Passive Consumers	●●	●	●	●	●	●	●	●	●
DO1: Smart Meter Redesign	●●●	●●	●●	●●●	●	●	●●	●●	●
DO2: Energy Democracy	●●	●●●	●	●●	●●●	●●●	●●	●●●	●●●
DO3: Energy Islands	●●●	●●●	●●	●●●	●●●	●●	●●●	●●	●●●
DO4: Conservation Alternative	●	●	●●●	●●●	●	●●●	●	●	●

Fig. 1. Option performance in relation to criteria.
Note: ●●● = strong performance, ●● = moderate performance, ● = poor performance.

saving, stating: "*we can't rely upon the end-users if we want change. It's got to be much bigger*" (C6) and "*We need to be realistic about how much people will engage. I suspect most people don't have the time or interest to worry about it*" (A1). Such views thus justified the need for strong and sustained government leadership in smart grid development.

4.3.2. Commercial Engagement

Commercial Engagement focussed on a smart grid driven by the increased involvement of major multi-national ICT companies utilising end-user data to develop new products and services and improve grid management. This option performed moderately for both professional and interested citizen interviewees with strong scores on environment, technical feasibility and user engagement criteria, and moderate scores in relation to all other criteria groups (data security, finance, governance, supply security). Interviewees from the ICT industry saw the key benefit of this option as being the introduction of a pro-innovation culture to the energy industry which they characterised as excessively risk averse:

> "*Risk aversion* [is] *a criterion for failure. Innovate and change quickly. And fail quickly. See what works and see what doesn't work. That's absolute anathema to most* [energy] *utilities…We need an injection of new management. Almost certainly from outside the* [energy] *industry*"
>
> (P1)

Interested citizen participants agreed, suggesting that stronger involvement of the ICT industry in energy management could boost user engagement. They saw the ICT industry as able to develop more '*creative options*' that would encourage people to '*sign up for it and take risks*' (C6), as well as helping to make smart meter data simpler and more relevant to people's everyday lives (C1). Some interested citizens, however, suggested that relying on commercial organisations was an "*abrogation of responsibility and knowledge to a third party when it comes to saving and reducing electricity bills*" (C2). They went on to question the trustworthiness of major ICT companies suggesting they would be unlikely to exploit user data in users own best interests (C2). Concerns were also raised over the inclusivity and potential inequity of a market-led approach to smart grid development, suggesting it would exclude those who "*might not want to pay to for a smart fridge, not trust it, can't afford it*" (A4).

4.3.3. Community Energy

Community Energy emphasised more community control and ownership over their energy requirements, motivated by climate concerns, energy security, rising energy bills and opposition to powerful utilities. This option performed most strongly out of all of the core options, perhaps surprisingly performing slightly better among professionals than among interested citizens. It scored well for equity, governance, technical feasibility and user engagement criteria, and moderately on all other criteria (data security, environment, finance, supply security). This strong performance was driven by the high levels of user engagement built-in to this option which was seen as helping to create a stronger sense of community ownership and involvement in energy system governance, breaking the control of major energy utilities, and introducing new thinking and practices to the energy industry:

> "*I think if you build in engagement, community ownership, conservation and data security you've got something pretty special…What I'm getting at is breaking the energy monopolies, greater competition, new market entrants, new ways of doing things, giving people the right to buy and sell their own power.*"
>
> (N2)

Stronger community involvement was also seen as useful to help identify and prioritise forms of energy generation that add value to local communities and increase equity and fairness (N1). Interested citizens saw this vision as valuable to help make a stronger '*connection*' (C1) between energy generation and local areas which could overcome potential resistance to localised generation, but some also expressed doubt over whether levels of '*energy literacy*' (C6) were sufficiently high within the population for this option to succeed at scale.

4.3.4. Passive Consumers

The final core option – *Passive Consumers* – focussed on growth in gas fired generators and interconnectors sufficient to balance variability from large scale renewable installations. In this option, grid balancing and energy management to achieve decarbonisation would occur automatically through smart technologies, demanding no action or engagement from consumers. This was the worst performing option overall, performing considerably worse than all other core and discretionary options for both professionals and interested citizens. It scored poorly on all criteria except for data security on which it performed moderately. This poor performance was driven by governance and user engagement criteria as participants across all sectors called generally for more active consumer engagement in the development and governance of smart grids (e.g. P1, P3, N1, N3, N4, G3, C7, C9). The technical feasibility of this option was also questioned as it was likened to '*pervasive computing*' (C3) in which technologies recede into the background of life. By contrast, some respondents suggested that this option would present a major technical challenge that would more likely complicate lives than make them simpler, demanding more active engagement rather than less:

> "*No matter how smart houses get, people will have to change their behaviour in order to survive in the future from an energy perspective. Whether it's avoiding peak power or spiralling energy costs, or whatever. We can't just sit back and wait for it to happen.*"
>
> (P3)

> "*Does more technology make your life simpler because it manages things that you have to otherwise think about or does it make it more complex because you have to think about all the things managing information for you? It sounds too restless, too confusing, too complex and there would seem to be quite a lot of risk of a lot people getting left behind as all this goes on.*"
>
> (A2)

Data security was also highlighted as a risk with this option because of the absence of active engagement and oversight from consumers (C2).

4.4. Option scoring: discretionary options

4.4.1. Smart Meter Redesign

Smart Meter Redesign explored a future in which end users were given greater ownership of their smart meter data and where the development of more advanced smart meters provides users with more choice over the smart technologies installed in their homes. This option was appraised by 9 participants in total, performing poorly overall particularly among professionals, although it performed quite strongly among interested citizens. The overall poor performance is explained by low scores for governance and supply security criteria, moderate scores on environment, equity, technical feasibility and user-engagement, and strong scores on data security and finance. Some professionals (P3, G3) saw a degree of smart meter redesign as unavoidable to avoid existing smart meters becoming redundant. Here, P3 suggested it could lead to cost savings if an approach of '*radical simplification*' was adopted wherein the "*meter would just be a very basic IoT data gathering device…and* [you] *do all the complicated stuff at the back-end…At the moment it's looking like £450 a pop* [for each smart meter], *whereas if you can make it £50 a pop, that's an* *awful lot of money you've just saved*" (P3). Both interested citizens and professionals saw some possibilities that redesigned smart meters could increase consumer engagement through the simplification of smart meter information (C1) or through improved in-home displays (A3), although C8 saw this as unlikely, arguing '*it will be very difficult to get people interested*'. Despite rating the option fairly strongly overall, interested citizens did raise significant concerns about it being wasteful – as it would render existing smart meters obsolete as witnessed with the UK SMETS1 rollout [71]; as potentially introducing '*radiation risks*' (C1), as being inequitable as it would likely favour those with the money to invest in the latest smart technologies (C1, C9), and as being more intrusive and less data secure (C8, C9).

4.4.2. Energy Democracy

Energy Democracy portrayed a smart grid in which citizens were heavily engaged in shaping the Governments vision for end-user engagement in the smart grid through a series of community workshops. This option was appraised by 9 participants in total, and was one of the best performing options overall among both interested citizens and professionals. The option scored well in relation to environment, governance, supply security and user engagement criteria. In general, participants expressed the sentiment that more democracy would help people to connect with and take control over the energy system which was seen as likely to promote environmental protection, as well as high levels of data and supply security. Professional respondents also saw this option as likely to democratise the energy market, reducing barriers for new and smaller suppliers (N1). Despite its strong performance overall, however, a high degree of scepticism was expressed around this option, with interested citizens in particular displaying a high level of uncertainty about its performance. The option performed moderately on data security, finance and technical feasibility criteria, and performed poorly for equity. Here, participants emphasised concerns around potential procedural injustice with this option, suggesting it would be unlikely to engage large numbers of people (P6) and that it could '*privilege certain sections of society*' (C3). Overall, however, there was strong support for the basic principle of energy democracy across all participants, with C3 suggesting that: "*Implementing the energy system in this new way* [c]*ould provide basic living and be an instrument to equalise society by reducing the social divide. It would be amazing if something like that could happen*" (C3).

4.4.3. Energy Islands

Energy Islands was characterised by citizens taking full control over their electricity supply through distributed generation and virtual power plants connected into end-user owned microgrids or 'energy islands'. This option was appraised by 15 respondents and was the best performing option overall, ranking top among interested citizens and second among professionals. This strong performance is explained by high scores for technical feasibility, data security, environment, finance and governance criteria and moderate performance for equity, supply security and user engagement. Technical feasibility was seen as key for this option, especially among professional respondents who saw a piece-by-piece approach to smart grid development as '*the only way it can really happen*' (P3). As with the Community Energy and Energy Democracy options, Energy Islands was similarly praised for '*changing the thinking*' (P1) in the energy sector by devolving responsibility to local areas. Interested citizens also emphasised that this option could help people make stronger connections between energy use and climate change, with C7 suggesting they would not "*mind outages, because it would remind people of the value of electricity…I am talking about maintaining connection to climate change and environmental issues. Outages could be symbolic of maintaining connection*" (C7). But, as also with Energy Democracy, significant scepticism was expressed around the procedural elements and potential injustice of this option, with participants concerned it would rely on a small number of active people, particularly from wealthier communities, resulting in everyone else potentially being '*led by people with other interests than your own*' (C2), or that it would be very hard to get people to cooperate or agree and could therefore become an expensive and high-risk option (C5). Finally, despite its strong performance for both finance and data security criteria, concerns were also raised about the loss of economies of scale in this option and that multiple citizen-owned and federated energy islands could be more vulnerable to terrorist attacks and hacking (A1, C2, P3).

4.4.4. Conservation Alternative

Conservation Alternative focussed on energy consumers choosing to pay towards a national programme of energy conservation and efficiency instead of the smart meter rollout and smart grid development. This option was appraised by 16 participants and performed poorly among both interested citizens and professionals, showing the second weakest performance out of all options. The option received low scores on data security, environment, governance, technical feasibility and user engagement criteria, but did perform strongly in relation to equity, finance and supply security. Whilst many participants scored the option poorly in its own right, they also suggested it '*should not be an alternative*' (A1) and that including high levels of energy conservation and efficiency in all options was a '*no brainer*' (C7). By reducing what people spend on energy use through energy efficiency, the option was also seen as having the potential to increase equity (C1). Others, however, suggested the option was very unlikely to work unless there was a sudden hike in energy prices: "*The only way to get people to stop using energy is make them really poor by making energy really expensive*" (C6), leading to negative impacts on equity. C1 also suggested the option was a way of '*trying to maintain the status quo*' (C1) by passing the buck for high levels of energy demand onto consumers and '*effectively saying there is nothing wrong with the grid as it is*' (C1).

4.5. Mapping option performance and rankings

Fig. 2 presents the aggregated final rankings of all options based on the combined appraisals of all participants. This shows three main levels of option performance among the core and discretionary options.

First, Energy Democracy and Energy Islands were the best performing options overall at the top of the range but in each case, and as with almost all options, there was quite a high degree of uncertainty (represented by the length of the bars) with the most pessimistic appraisals of each of these options falling below those of other options. The generally strong performance of these options was driven by the strong levels of citizen engagement and democratisation that was at the core of these options, and they were also praised for bringing new actors and ways of thinking into the energy system and having the potential to increase the connection between energy, climate change and communities. Concerns were raised, however, around the equity of these options, particularly in relation to potential procedural injustice if these options came to rely on only a small number of active citizens.

Second, Community Energy, Commercial Engagement and

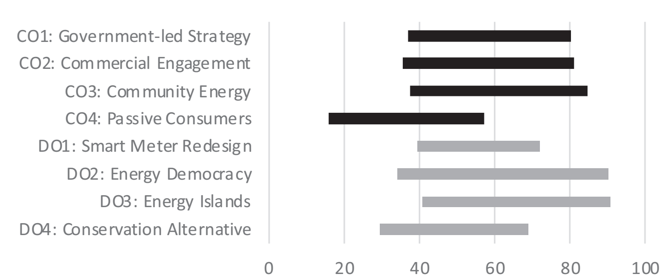

Fig. 2. Aggregated final rankings of all options.
Note: core options are shaded black, discretionary options shaded light grey. The length of the bars represents the mean difference in performance under optimistic and pessimistic assumptions. The x axis is a relative scale from 0 (lowest performance) to 100 (highest performance).

Government-led Strategy and Smart Meter Redesign performed moderately overall. In each case, participants liked the distinctive governance arrangements represented by these options. For example, Community Energy was liked because it introduced new forms of ownership and control. Government-led Strategy was praised for offering strong and long-term leadership seen as necessary for infrastructure development, and Commercial Engagement was seen as offering much needed innovation and new thinking to the energy industry from the ICT sector. Each option also raised concerns however. Community Energy was seen as hampered by a lack of energy literacy in the wider population, Government-led Strategy was seen as unlikely to motivate user engagement, whilst Commercial Engagement was seen to risk compromising data security with the motives and trustworthiness of commercial organisations widely questioned.

Third, the lowest performing options were Passive Consumers, Smart Meter Redesign and Conservation Alternative. In these cases, participants commented that these options risked preserving the status quo and failing to bring about meaningful change to the energy system. Passive Consumers was seen as placing responsibility onto users and letting more powerful actors off the hook, Smart Meter Redesign was critiqued for being potentially wasteful by rendering existing smart meters obsolete, whilst Conservation Alternative was understood as potentially implying that the energy system is fine as it is and requires only efficiency improvements rather than the more fundamental overhaul of the way the system is run, by whom and for what ends that several participants (e.g. P1, N2, C1, C6) called for.

Fig. 3 shows the final rankings of each option disaggregated by interviewee sector. In general, there is a lot of similarity across the different sector perspectives regarding the final option rankings. The length of the bars demonstrates quite high levels of uncertainty all round, with slightly more uncertainty among interested citizens' appraisals than among professionals. There are, however, a few notable differences between sector perspectives. Private sector participants, and particularly those working in the ICT industry (P1, P2 & P3) were notably more favourable towards Commercial Engagement than other sectors and also ranked Energy Democracy high with low levels of uncertainty. This is consistent with strong calls from participants in this sector to introduce a new culture and new ways of thinking to the energy industry, and to democratise the energy market by reducing barriers to entry for smaller energy providers. Participants from the Government sector ranked Smart Meter Redesign fairly high compared to other sectors, often mentioning that this was essential to avoid existing smart meters becoming out-of-date and obsolete. NGO participants strongly emphasised the value of forms of local control and ownership throughout their interviews and this is represented by Community Energy being the top ranked core or discretionary option among this group. In short, whilst there was broad agreement overall, participants from different professional sectors each identified different challenges and requirements for future smart grids, and each seemed to prefer options that advanced their own sectors contribution to smart grid development.

Among interested citizen participants the overall rankings were again broadly similar although with slightly higher rankings for Smart Meter Redesign and Government-led Strategy than for other sectors. Whilst the final rankings were similar however, the nature of interested citizen appraisals of these options was quite different and focussed significantly more on concerns around the everyday operation of the different options. Interested citizens variously emphasised issues around their local environment, their health, privacy, security and trust regarding their personal data, and the practicalities of different forms of user engagement. Here, interested citizens were very quick to point out potential procedural injustices with different options, such as around who was likely to engage and what that engagement would demand, whereas professional interviewees were more likely to emphasise distributive issues around who could afford smart technologies for example. A final key difference between interested citizens and professional interviewees emerged in relation to their thoughts about the acceptability of supply constraints. Where professional participants widely dismissed the possibility of supply constraints as simply '*not acceptable*' (A4). Interested citizens were much happier to accept them as a necessary price to pay in efforts to address climate change suggesting they may help people to connect energy use with environmental

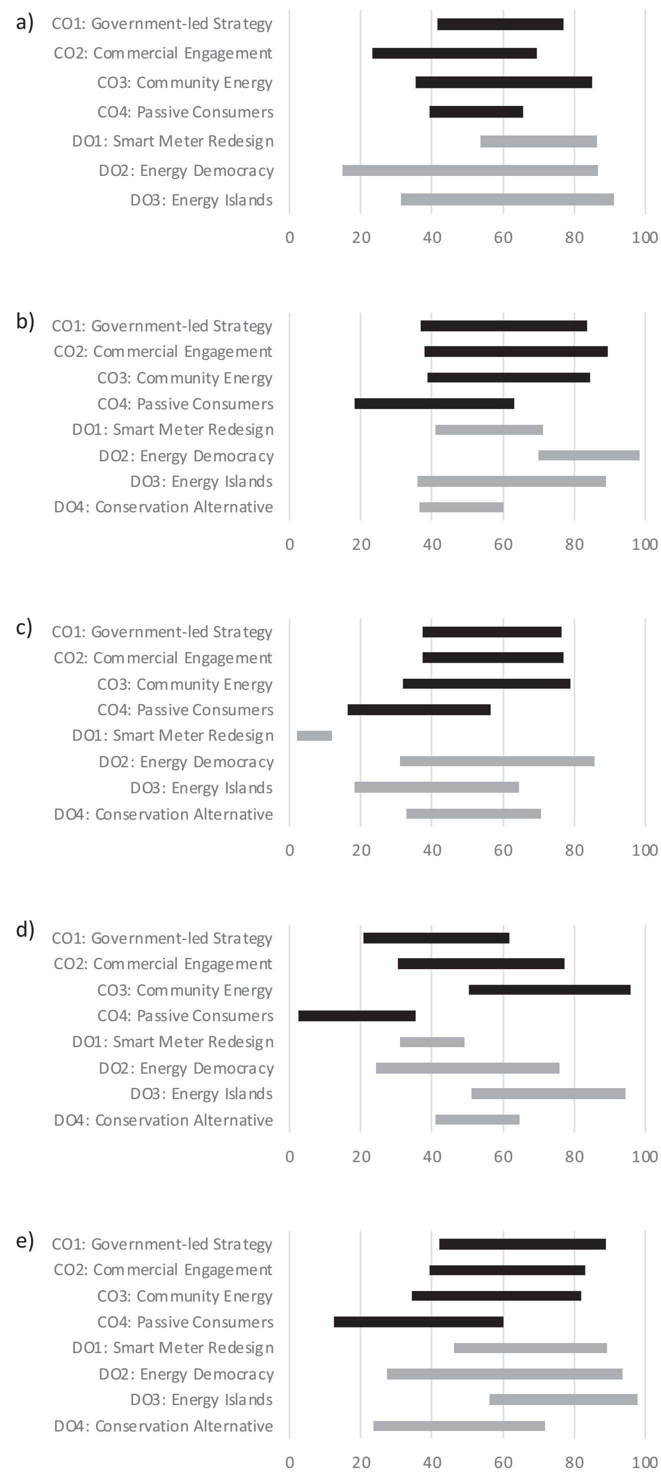

Fig. 3. Final option rankings disaggregated by interviewee sector.
Note: a) Government; b) Private Sector; c) Academics; d) NGOs; e) Interested citizens. Core options are shaded black, discretionary options shaded light grey. The length of the bars represents the mean difference in performance under optimistic and pessimistic assumptions. The x axis is a relative scale from 0 (lowest performance) to 100 (highest performance).

damage, and also felt that intermittent blackouts could be easily planned and managed.

Overall, the key message from these option rankings is that there were strong calls from all sectors for significant change in the energy system. Those options that were perceived as keeping the energy system the same or preserving the status quo were consistently appraised negatively. In contrast, there was strong support for more distributed smart grid visions and solutions that sought to democratise the energy system by introducing new actors, new forms of ownership and decision-making and higher levels of user and community engagement. As part of this, however, participants emphasised concerns around the equity of future smart grid visions emphasising both procedural and distributive justice. These issues will need to be addressed carefully in the future development of smart grids.

5. Discussion and conclusions

In this paper we have presented a systematic mapping of how diverse actors variously appraise and anticipate the implications of smart grid visions in relation to different societal values. Our analysis demonstrates that the future success of smart grids developments is not only a technical matter, but crucially depends on them being socially smart as well. In doing this our analysis has reached beyond the three main areas of existing social science research on smart grids outlined in Section 2, to address the 'social smartness' and societal dimensions of smart grid developments. Our results show that the actors, visions, values and practices shaping future smart grids should not be considered separately because they are both interrelated and distributed across sociotechnical systems. In these respects, our findings concur with recent theoretical and conceptual developments that emphasise the diverse and distributed nature of sociotechnical transitions whether in terms of imaginaries [21], participation [72], social practices [73] or innovations [74]. In the following discussion we consider how such distributed qualities are a cross-cutting feature of three key findings from our paper, namely on: (i) the sociotechnical visions and pathways of future smart grid developments, (ii) the value-based criteria that (should) shape such developments, and (iii) how the future implications of such developments can be anticipated and made more socially responsible.

First, with regards to sociotechnical visions and possible future pathways, we have moved beyond analysing state or science-centred sociotechnical imaginaries of smart grid developments [22,24] to consider how such imaginaries and future pathways are also produced and appraised by distributed actors in civil society and the wider public sphere [21,62]. Our analysis has shown how possible future smart grids are not fully expressed by a single vision. They are subject to multiple perspectives, visions, hopes and concerns from different sectors and actors in society. We have documented how there are many different possible pathways and future trajectories along which a future smart grid may evolve. We have also seen how these different paths are judged differently by actors to reveal key tensions and points of contestation. For example, by referring to Fig. 3 (above) it is possible to gauge the differences in perceptions of pathway viability from across different sectors. Moreover, looking across the different option appraisals, we can see potential points of tension in future pathways. For instance, there was strong support for community energy and energy democracy, but significant scepticism around the possibility for large-scale active citizen engagement. Similarly, participants expressed concerns relating to data privacy and security, and yet wide-scale availability of smart meter data could be seen as a pre-requisite for the local, community-driven smart grid systems that were positively appraised. From this we conclude that any attempts to govern and steer developments around a future smart grid will need to be more open and responsive to these diverse points of view and actions, not least because they could otherwise represent barriers to successful implementation (see also [3,22,25]). Furthermore, the diverse perspectives and expectations brought forward by the participants in our study emphasise how attempts to steer developments around future smart grids will not only be centralised. Rather, they will be formed by multiple distributed practices, actions and societal engagements across public and private sectors and in civil society (cf. [28,46,58,75]). As we showed in Section 4, when considering contending pathways for smart grid development, there is some preference across the MCM appraisals towards greater democracy in the energy system, community energy and new network architectures that are potentially more resilient under high levels of renewable energy generation and active demand response. There was less support for smart grid development pathways that depend on centralised control by Government or the energy industry, whilst visions that see smart grid development being removed from publics in automated ways (such as 'consumer passivity') performed even less well across the respondents.

Second, in eliciting the socio-political issues and criteria associated with smart grid developments our study has reached beyond the frame of 'representative' publics and consumers enrolled into existing studies of public attitudes and 'social acceptance' of smart grids (e.g. [33]) to include a wider diversity of distributed actors ranging from users, community groups, interest groups and NGOs through to academics, national and local government, regulators, energy unities, and technology companies. Our analysis has systematically identified criteria and matters of concern that different actors in society feel should be taken into account for future smart grids to be successful, namely: data security; environment, equity, finance, governance, supply security, technical feasibility and user engagement. What is particularly significant here is how the range of criteria developed by participants in our study emphasise that the success of future smart grids goes beyond solely technical considerations, and beyond the dominant framework of 'the energy trilemma' [17,76], to also include a range of social, political and ethical considerations as well. These findings echo key public concerns about the governance of a range of emerging technologies both within the energy field (e.g. [39]) and beyond (see [77]). To date, however, these dimensions of what it means to be socially (as well as technically) smart have not been sufficiently acknowledged in energy research, policy or practice. Moving forward, a key consideration is whether new paradigms from distributed stakeholder sectors are entertained and smart grids develop in cooperation with a wider range of stakeholders to promote equity and fairness. Or, whether the status quo is maintained by incumbent interests whose perspectives often seem to shutdown debate and discussion about what smart grids should be [22,25]. Recent focus on 'smart local energy systems' (e.g. [67,78,79]) and growing emphasis on geographical location and scale (e.g. [59,60]) suggests attention to more distributed and place-based perspectives is increasingly being recognised as integral to smart grid development.

Third, rather than explore how existing smart grid developments interact with the dynamics of social practices in communities and everyday life (e.g. [49,51,55,58]) our analysis opens up the possibility to consider a wider distributed system of practices (cf. [73]) and decision-making through which the development of smart grids will be shaped in the future. Which brings us to the final main implication of our study. If current governance arrangements struggle to acknowledge what it means to be socially smart, this raises important questions for how the criteria identified in our MCM study can be taken into account in the multiple distributed decisions that will contribute to the formation and reformation of future smart grids. Our analysis suggests that because the processes of policy-making, decision-making, design and innovation that will lead to future smart grids will be distributed and multiple, then strategies for accounting for the social dimensions of these processes will themselves have to be diverse rather than centralised, unitary and prescriptive. In addition, there is a need for tools, devices, procedures and ways of being that can build 'real time' reflection over what it means to be socially smart - incorporating concerns over equity, inclusion, directionality, privacy and trust - into smart grid design and innovation processes. In this respect, smart grid developments should engage more closely with frameworks for responsible innovation, anticipatory governance and energy justice (e.g. [77,80–83]). These have been applied to other emerging technologies and energy objects, but are yet to fully inform the socially responsible development of smart grids (although see [41,84]). The distributed nature of smart grids and their imagined futures in turn creates challenges for established frameworks for responsible innovation and energy justice.

To conclude, our analysis points to four strategies as promising ways of embedding the criteria for and understandings of social smartness developed in this paper into distributed smart grid innovation processes. First, there is a need for open and discursive spaces where smart grid decision-makers and innovators can interact with social scientists and/or actors in wider society to reflect on what it means to be socially (as well as technically) smart and consider future social and ethical implications of smart grid developments (cf. [85]). A second possibility is the development of tools that allow distributed decision makers to go through processes of reflection over the social, ethical and justice dimensions of their innovations and decisions in 'real time'. Here, the socio-political criteria presented in Section 4.2 could be formed into sensitising questions to encourage actors engaged in smart grid developments to consider socially smart criteria in their work. For example, in the case of the equity criterion and concerns about procedural and distributive justice, a key sensitising question would be: to what extent is this smart grid development fair in the distribution of benefits and risks associated with its implementation? Third, processes of organisational learning and capacity building [86,87] that help raise awareness and develop cultures that are more reflective of the social meanings of smart can help incorporate such considerations into every day and ongoing smart grid-related practices and decisions. Fourth, and finally, whilst our study has identified core social values, criteria and visions that can guide future smart grid developments, these should be open to ongoing public scrutiny and revision in response to changing circumstances through diverse and distributed participation [88] thus enriching the above suggested interventions.

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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