Transitions, disruptions and revolutions

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Transitions, Disruptions and Revolutions:

Expert views on prospects for a smart and local energy revolution in the UK

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Highlights

- Reports findings from a major 'Policy Delphi' expert survey on UK energy futures
- Survey is designed to consider the 'smart and local energy revolution' proposition
- Results question the likelihood and desirability of a wholesale energy revolution
- Whole system analysis should go beyond any single uniform transition narrative
- Energy transition narratives are socially constructed and contestable

Abstract

Alongside ambitious targets for economy-wide decarbonisation, a 'smart and local energy revolution' narrative has recently emerged in energy policy and research. To consider the energy revolution proposition, this paper presents findings from a Policy Delphi survey of interdisciplinary energy researchers and stakeholders (n=113) on alternative transition paths (disruptive or continuity-led) for the UK energy system. The paper includes quantitative and qualitative survey findings on a number of social and technical aspects of the energy revolution proposition: system governance, security and flexibility arrangements, power sector decarbonisation, the future of large supply firms and energy policy priorities. The results suggest that rather than a wholesale revolution, the UK's energy transition over the next two decades will involve a mix of disruptive and continuity-led elements. Experts differ on a number of issues associated with the energy revolution proposition, including the impact of demand side response on whole system flexibility, and whether energy systems are best governed at a local or national scale. However, rather than having fixed orientations to either disruption or continuity-led change, most experts respond on an issue-by-issue basis. The energy revolution proposition is socially constructed and contestable, and whole energy systems policy and research should go beyond uniform transition narratives.

Keywords

Whole system transition; energy revolution; disruption; smart; local; Policy Delphi

1 Introduction

There has been a radical turn in recent UK energy policy rhetoric. While this has a number of features, it involves strong commitments to 'smartness' (or digitalisation) and 'localisation' (or decentralisation) – often summarised as a 'smart and local energy revolution'. Less than a decade ago, the UK Government considered that there was "no reasonable alternative" to a massive re-investment in the UK's national, centralised system of electricity generation and transmission, concluding that "the Government does not believe that decentralised and community energy systems are likely to lead to significant replacement of larger-scale infrastructure" (DECC, 2011, p.24).

Six years later, the UK Government launched a new economy-wide Industrial Strategy, including a *Prospering from the Energy Revolution* theme aimed at developing "world-leading local smart energy systems" (HMG, 2017, p.45). Soon after, the then Secretary of State for Business, Energy and Industrial Strategy heralded a new era of energy system change, contrasting a historic emphasis on "a centralised grid that would deliver secure supplies more cheaply than did [sic] decentralisation" with a future characterised by "embedded generation co-located with storage, demand-side management, energy efficiency and AI-enabled control" (Clark, 2018).

This revolutionary turn has already gone beyond rhetoric: a raft of spending commitments followed the publication of the Industrial Strategy White Paper, and the UK Government has committed to investing over £100m on *Prospering from the Energy Revolution* related activities, including a new *Energy Revolution Research Consortium* (UKRI, n.d.). Promoting 'smart local energy systems' is also a key pillar of the Scottish Government's Energy Strategy

(Scottish Government, 2017) and enthusiasm for a smart and local energy revolution is a defining concern for some key publicly funded UK innovation bodies, such as the Energy Systems Catapult (New, 2016).

An energy revolution narrative is evident internationally, reflecting the reducing cost of some small scale generation and storage technologies, the impact of digital technologies on energy network management, and a political trend toward regionalisation and devolution. A raft of studies by energy consultancy firms and industry associations has presented the case for a decentralised energy revolution; for example, the President of the UK's Energy Institute stated that "Today's energy system is undergoing a quiet revolution, driven by an everchanging global political landscape, climate change challenges and a range of innovations influencing energy consumption" (Energy Institute, 2017, p.4). The consultancy firm PwC has argued that: "From a scale-driven, centralised and standardised model, the sector is set to evolve to one that is digital, distributed and personalised" (PwC, 2016, p.3). In its 2018 *Energy Visions* report, PwC declared that the energy sector had entered a "decade of disruption" (PwC, 2018).

The concepts of energy disruption and revolution are also attracting academic interest. Jalas et al. (2019) note that energy disruption metaphors are in frequent use in strategic energy research agendas, with some emerging technologies seen as constituting a major disruption in energy systems. Wilson and Tyfield (2018) consider a range of different academic perspectives on the links between energy transformation and disruptive innovation. Johnstone et al. (2020) note that the notion of 'clean energy disruption' has become widespread, and go on to consider how it has manifested across a number of social and technical dimensions in German and UK energy systems. Lindberg et al. (2019) analyse alternative energy pathways in EU energy policy documents, distinguishing between decentralised (high disruption) and centralised (low disruption) transition paths, while Brisbois (2020) considers the disruptive impact of decentralisation dynamics on energy transition policy-making in Canada.

From a holistic and interdisciplinary perspective, assessing the smart and local energy revolution proposition is challenging. While the suggested benefits include community empowerment, local economic growth and capturing the benefits of demand side flexibility (Hall and Roelich, 2015; Braunholtz-Speight et al., 2019), there are also some concerns. A UK parliamentary committee identified some risks of energy decentralisation, including piecemeal development and an erosion of universal service provision and cost socialisation (UK Parliament, 2017). Large integrated energy systems continue to offer some economic, technical and societal advantages, and scale economies remain significant in many areas (McKenna, 2018) – indeed, they have driven much of the UK's decarbonisation achievements over the past two decades (BEIS, 2019).

There are also more socio-historic reasons to question (or at least problematise) revolutionary and disruptive narratives of change. For Paul Edwards, a historical analysis of infrastructure may usefully challenge more immediate disruption narratives (Edwards et al., 2009; see also Edgerton, 2010). While emerging data technologies create new possibilities for decentralised, reconfigurable infrastructures (Egyedi and Mehos, 2012), energy infrastructures have historically often been 'accomplishments of scale', as local systems are joined together over time (Jackson et al., 2007).

Other scholars have highlighted the politically contested nature of infrastructure system building, across municipal, national and international scales (Van der Vleuten et al., 2013). In the UK, the historic shift away from municipal and regional control of energy infrastructure was itself contested (Hannah, 1979; Hughes, 1983); Arapostathis et al. (2014, p.87) described the shift from municipal 'town gas' supply to GB-wide system integration in the 1960s and '70s as a 'complex and uncertain socio-technical process'.

Scale-based contestations are also evident in future infrastructure visions and scenarios. Hommels et al. (2013) observed how both centralisation and decentralisation narratives are seen by their respective advocates as compelling solutions to system challenges and vulnerabilities. Schiølin (2019, p.4) warns that "revolutionary dreams" in futures narratives – using the cover of supposed inevitability – are often ways to exercise power and social control. Weijers (2012) also emphasised that infrastructure scale dynamics should be seen as socially, technically and politically contested. Lagendijk and Van der Vleuten (2013, p.97) concluded that the key research task was to "highlight and interrogate … entanglements between international, national and local processes, not obscure and erase them".

Here, we consider this analytical challenge in the context of contemporary energy transitions, and the smart and local energy revolution proposition. We report selected findings from a large survey of energy experts on the likelihood and desirability of distinctive transition paths for the UK – one more disruptive and locally oriented, the other more continuity-led and nationally oriented. The paper proceeds as follows: Section 2 introduces our survey research method and discusses methodological aspects and reviews some similar studies; Section 3 presents selected survey findings on selected issues related to the UK's smart and local energy revolution narrative; Section 4 summarises and discusses the findings alongside other studies and Section 5 concludes.

2 Research Method

2.1 Policy Delphi and Energy Transitions

Delphi is a widely used expert elicitation method, founded on the suggested benefits of interaction and iteration of expert views using multi-round surveys (Linstone and Turoff, 2011; Dayé, 2018). The method has been used in different forms in futures studies since the early 1970s, and has been applied in UK Foresight studies, European ERA-net research for science and technology strategy (Miles et al., 2016) and in some recent energy transition studies in Europe (BDEW, 2015; Jalas et al., 2019).

Several different versions of the Delphi method have been developed (Miles et al., 2016); among these, *Policy Delphi* is distinctive in that, rather than developing consensual 'best guesses' to feed into forecasting exercises, it recognises that policy problems typically have multiple discourses and viewpoints, dispersed by region, role and discipline (Turoff, 2002, cited in de Loë et al., 2016, p.82).

Policy Delphi aims to "explore or expose underlying assumptions or information leading to differing judgements" (Turoff, 1970, p.149) and "reveal options and alternatives, points of agreement and disagreement, clarify arguments and uncover the strength of evidence associated with diverse viewpoints" (de Loë et al., 2016, pp. 78-79).

De Loë et al. (2016, p.80) note Policy Delphi's value as an interdisciplinary tool, as it is able to address "complex and intertwined subjects" that cross over disciplinary boundaries and range across political, environmental, social and technological considerations. An Expert Elicitation Task Force convened by the US Environmental Protection Agency (EPA, 2009, p.84) noted that for these kinds of problem, "differences in response may result from different paradigms by which experts view the world". In these situations, reconciling expert differences may be imprudent (Morgan, 2011) – rather, the need is to map different opinions, and understand the reasonings behind them. The breadth of the issues involved in Policy Delphi studies, spanning multiple sectors and groups, warrants a lengthy and iterative consultation process (Devaney and Henchion, 2018).

Given these aims, it is perhaps surprising that Policy Delphi has found relatively little application at the research-policy interface of sustainable energy transitions, and there are very few close precedents to our large scale and broad ranging expert survey. In their critical review of energy scenario methods, Trutnevyete et al. (2016) – although not directly referencing Policy Delphi – recommended incorporating a diverse range of experts and stakeholders, and of counter-posing different views in a structured way. Even so, recent Delphi studies of energy transitions – and energy expert surveys more generally – tend to seek the majority view of the response base rather than mapping and exploring areas of disagreement. They also tend to be technology-centric; for example, Grafakos and Flamanos's survey of European energy experts (Grafakos and Flamanos, 2017) is aimed at quantifying the extent of agreement or disagreement across a series of technology focussed issues.

The main concerns of the Smart Energy Finland (SET) Delphi study (Ahonen et al., 2018; Jalas et al., 2019) were also technological, in terms of gathering expert expectations of the impact of a range of disruptive technologies, to consider how the Finnish energy sector might adapt and prosper – reflecting the research consortium's base in supply side technical expertise. The SET survey's alternative transition pathways focussed on alternative future technology portfolios rather than alternative socio-technical combinations. Jalas et al. (2019, p.51) noted that after the SET study's focus on technology was met with criticism, it was broadened to make a 'reflexive space' for considering the potential impacts of smart energy technology, recognising that need to "evoke uncertainty and problematize energy futures"; however, they didn't problematise the dominant narrative of disruption.

A closer parallel with our study is the 'Delphi Energy Future 2040' study (hereafter 'DEF') (BDEW et al., 2016). This shared our concern to "connect specialists from different areas of expertise", combine different perspectives and identify dissenting as well as majority opinions (ibid., p.4). DEF's survey questions covered a wide range of social and technical aspects of disruptiveness, including system decentralisation and bottom-up social movements. As in our study (see 2.2, below), these aspects were presented as a series of propositions of energy futures, with expert respondents invited to agree or disagree with the proposition. The DEF report also includes illustrative comments representing respondents' alternative views – although there is little attention to quantitatively or qualitatively analysing the reasons for disagreement.

Expert surveys are also conducted by some energy consulting firms and industry associations (e.g. PwC, 2019; Energy Institute, 2019). These tend to adopt a business strategy perspective. For example, the UK's Energy Institute conducts an annual 'Energy Barometer' survey which has some similarities to our study, in terms of its UK national focus, and in its attention to both mapping the spread of views across the survey sample and reporting some respondents' comments. However, rather than exploring alternative UK energy transition narratives, the Energy Barometer's main concern is to develop a sector view on issues such as policy instability and investment risk – the 2018 survey noted the high degree of consensus on most issues (Energy Institute, 2018, p.35). It also draws on a mostly business response base: in the 2018 survey only 20% of respondents were from academia and research (ibid.). A brief comparison of our results with those in the DEF and Barometer surveys is presented in the discussion section of this paper (see 4.3).

2.2 Survey Design

Our Policy Delphi survey was designed to map and understand expert opinion on contrasting *disruptive* and *continuity-led* scenarios for the UK energy transition. As exploratory scenarios, these offer "internally consistent and plausible alternative storylines describing a number of possible longer term futures, often including trend-breaks" (McDowall and Eames, 2006, p.1238). The disruptive scenario resembles the 'smart and local energy revolution' narrative described above, in that digitalisation and smaller scale generation and storage innovations, and a growing emphasis on local energy governance, encourage a radical decentralisation of the system, both technically and institutionally. By contrast, in the continuity-led scenario, the UK's energy transition is pursued mainly by repurposing existing organisations and infrastructures, without fundamentally disrupting or rescaling the system.

Our survey invitees were identified from a range of sources: academic researchers associated with the UK Energy Research Centre (UKERC), other senior researchers in the 'whole systems' theme of the UK Research Councils / UKRI energy research programme and through 'snowballing' with assistance from the UKERC community. Stakeholder invitees included analysts and officials working in public policy, intermediary and advisory roles, third sector organisations and business stakeholders. Among business stakeholders, we purposely sought to strike a balance between 'incumbents' (i.e. those with longstanding energy interests) and 'disrupters' (those with emerging interests). Invitations were emailed to over 600 UK-based individuals across these different groups – a large and heterogeneous invitation list.

The survey was designed to cover a broad range of topic areas, across both the UK energy system as a whole and specific sectors such as heating, power and transport. The year 2040 was chosen as the time horizon for most of the survey questions, to strike a balance between unconstrained change over long timescales and highly constrained change over short timescales (Jalas et al., 2019). For each survey question, participants were presented with short propositions, questions or suggestions describing features of the future UK energy system or the transition pathway between now and 2040.

Consistent with other Policy Delphi studies (de Loë, 1995), participants were asked to assess the likelihood (or in some cases desirability) of the propositions on a 4-point Likert scale, ranging from 'highly likely' to 'highly unlikely', with an additional option of 'undecided/cannot say'. For each question, respondents were then invited to explain their reasoning in a text box, mentioning any relevant sources of evidence that informed their view. In this way, the survey went beyond mapping expert views, to explore the reasoning and evidence bases involved.

In the second round of the survey, we presented the whole sample quantitative Likert-scale results from Round 1, and also a summary of the different reasonings behind different Likert scale answers, as expressed in respondents' free text comments; we then invited respondents to respond to the sample-wide results, confirm or revise their own first round answer, and offer any reasons for maintaining or changing their view. Qualitative responses were coded in NVivo, and were analysed independently by the two authors, to identify the full range of perspectives and reasonings. Any differences of interpretation of qualitative data were extensively discussed and then reconciled by the authors.

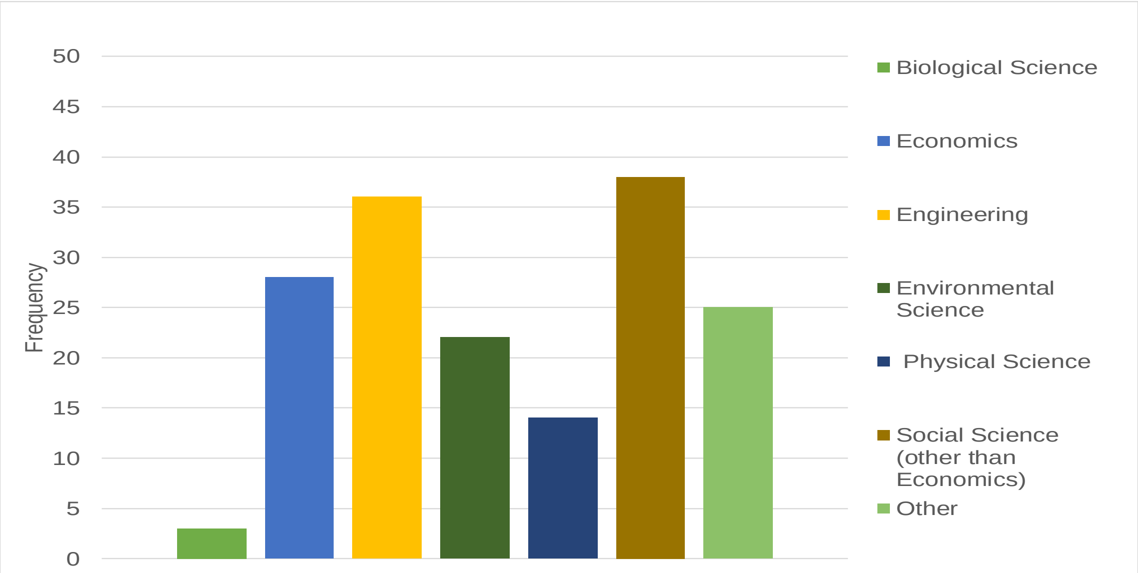
2.3 Survey Sample

Our survey was conducted over two rounds in late 2017 and in early 2018. 127 people completed Round 1 (a 22% response rate), 69 of whom also completed Round 2 (a 54% response rate from Round 1), although not all respondents answered all questions, and only 113 respondents answered the specific questions reported in this paper. The overall sample sizes and response rates are within the ranges reported by other comparable Policy Delphi studies (Nowack et al., 2011; de Loë et al., 2016), and suggest a high level of interest among energy researchers and stakeholders, particularly since our survey was relatively lengthy, with over 20 detailed questions across nine topic areas, and over 100 specific prompts inviting a response.

The first section of the survey gathered information about our respondents. Round 1 respondents came from varied disciplinary backgrounds (Figure 1). Of those who declared a disciplinary affiliation, 30% identified as social scientists (other than economists); 28% as engineers; 22% as economists; 17% as environmental scientists; 11% as physical scientists and 20% as ‘other’. (The figures sum to over 100% because many respondents identified themselves as having multiple disciplinary affiliations). The most common ‘other’ disciplinary identities included business, complexity science, energy modelling, interdisciplinary research, maths and operational research, policy, statistics and technology assessment.

Most Round 1 respondents described themselves as having a senior role (68%); 16% had a mid-career role and 16% an early career role. Geographically, respondents were well distributed across the UK, with 83% based in England (just over one-third London-based, the others spread across all English regions), 12% in Scotland and 4% in Wales.

Figure 1: Disciplinary affiliations of the Round 1 sample



The Round 1 sample comprised 45 non-academic stakeholders (35% of respondents), 45 non-UKERC academic researchers (35%) and 37 UKERC academic researchers (29%), so that the response base was just under two-thirds academic researchers and just over one-third non-academic stakeholders. Response rates were slightly higher for UKERC invitees (23%) compared to non-UKERC researchers (20%) and non-academic stakeholders (19%) – perhaps reflecting our regular interactions with UKERC during survey development. To be inclusive with respect to the UK's interdisciplinary research community we chose not to filter-out responses in order to 'even-up' the different categories of respondent.

There are varied views in the Delphi and Policy Delphi literature about the desirable composition of a Policy Delphi response base. Many analysts suggest that respondents should be as diverse as possible – Winkler and Moser (2016, p.72) argue that "heterogeneity is valuable in mitigating all of the major biases that are at play in Delphi studies". Beyond this, there is no agreed formula (Winkler and Moser, 2016; Dayé, 2018). Devaney and Henchion (2018) recommend a mix of breadth, depth and objectivity among respondents, including both existing and potential 'value chain' holders alongside more independent experts.

Needham and de Loë (1990) distinguish between 'subjective experts' (e.g. business representatives), 'mandated experts' (policymakers, regulators etc.), and 'objective experts' (publicly funded researchers). While a mix of these types is seen as useful, having a majority of researchers is seen to offer some advantages, as the response base is then considered less influenced by vested interests. However, researchers may be biased towards particular innovation breakthroughs and research in particular fields, and they may have limited commercial understandings. Some analysts suggest that mandated experts are more neutral arbitrators of different interests (Devaney and Henchion, 2018).

To mitigate systematic bias in our academic response base, we chose not to issue invitations to researchers in domain-specific parts of the UKRI Energy Programme, as we considered this to be more likely to introduce technology- or solution-specific orientations or biases. UKERC is a large, independent and interdisciplinary network of academic researchers (we invited all research members of UKERC as of late 2017, n=162). While UKERC is dedicated to supporting a sustainable energy transition for the UK, it does not advocate or preferentially generate evidence for particular energy transition pathways in terms of scale, technologies, or social practices. Our non-UKERC academic invitees (n=220) were all investigators (grant holders) in the 'Whole Systems' theme of the UKRI Energy Programme, and as such can be expected to have a relatively holistic and interdisciplinary perspective on UK energy system change.

We invited 232 non-academic stakeholders. Following Needham and de Loë's (1990) expert typology, our non-academic respondents (n=45) were almost equally divided between mandated experts (47%) and subjective experts (53%) (see Appendix A). Further categorising the subjective experts, in terms of having a clear orientation towards either disruptive or continuity-led energy transition was not possible in most cases, and 54% of subjective experts are considered to have neither; 25% can be considered to be oriented to continuity-led change (as they have mostly incumbent vested interests) and 21% to disruptive change (as they have mostly emergent vested interests). However, the number of subjective experts with clearly identifiable orientations is small: only 11 respondents (9% of the total response base), and overall, the vast majority of our respondents have no clear upfront affiliation to either continuity-led or disruptive change.

An important methodological concern for holistic interdisciplinary surveys is the level of expertise of individual respondents. At the start of our survey, participants were asked to self-assess their level of expertise across the nine different topic areas of the survey, in terms of being a ‘domain expert contributor’, a ‘well informed non-domain expert’ or having a ‘non-expert lay view’. For all nine topic areas, more respondents described themselves as being well informed non-domain experts than domain experts. The ‘energy system overall’ topic had the highest level of self-assessed expertise, above any domain-specific topic. Our results therefore reflect more generalist, interdisciplinary energy expertise than domain-specific specialist expertise, reflecting our focus on the UK’s ‘whole energy systems’ academic research community.

Again, the methodological literature suggests that this may be an advantage. For Policy Delphi surveys that address complex and open socio-technical systems, no single respondent can hold an expert opinion across all the different areas involved, especially if the system is expected to undergo a multi-faceted transition (Devaney and Henchion, 2018). In these contexts, specialist expertise offers limited foresight, and multi-domain experts may be better able to anticipate change (Tetlock, 2005; Grisham, 2008). According to Linstone (1975, 581; cited in Needham and de Loë, 1990) specialists tend to focus on a subsystem rather than system whole, and in such situations ‘generic functional knowledge’ may hold greater value (Tetlock, 2005).

Another relevant methodological issue is Delphi respondents' propensity to engage with others' views and reconsider their own views over successive survey rounds. 'Belief persistence' is widely found in multi-round Policy Delphi surveys (Makkonen et al., 2016). For Winkler and Moser (2016), a low propensity to change view reflects 'hypothesis-based filtering', as respondents tend to adopt a position and then select evidence and arguments to defend it; Bolger and Wright (2011) referred to it as 'egocentric discounting' – weighting one's own opinion above the views of others. In this context, Devaney and Henchion (2018) concluded that any recognition whatsoever of others' views should be seen as a distinct success of the Policy Delphi method. The apparently very low level of interaction seen in our results also overlooks the implicit, unstated way that many Delphi survey respondents react to the views of others, perhaps reflecting participant fatigue (Dayé, 2018).

3 Results

3.1 Introduction

This section presents selected findings from our Policy Delphi survey, on particular issues related to the smart and local energy revolution proposition for the UK energy system transition: energy system governance, security and flexibility arrangements, power sector decarbonisation, the future of large supply firms and policy priorities.

In our Round 2 survey, the vast majority of all Likert scale responses (89%) involved no explicit response or change to Round 1 results. Of the 11% of responses which involved either a change of view or an explicit response to Round 1 results, over three quarters (76%) either offered no reason for changing or gave a reason which didn't explicitly reference others' views. Among the small proportion of responses which explicitly referenced others' Round 1 views, most (59%) maintained their own view – only 41% involved a change of view. This means that, although most Round 2 participants (71%) changed at least one of their answers, only 1% of all Round 2 individual responses involved *both* an explicit reference to others' Round 1 views *and* a change in their own view.

Given the very limited number of changes of view in Round 2 results, and the much larger number of respondents in Round 1, this section presents results mostly from Round 1 – although a short discussion of Round 2 findings is also given for most issues. (To reduce participant fatigue and avoid repetition, the Round 2 survey omitted some Round 1 questions).

Alongside the Round 1 quantitative results, a range of different written responses is included, so as to demonstrate the variety of respondents' views and reasonings. In line with mixed methods literature (Small, 2011), the qualitative data was analysed thematically to reveal the common themes, key areas of divergence, and surprising insights underlying the Likert scale responses to each proposition in the survey. For each question, we present illustrative reasonings associated with majority / dominant and minority / marginal Likert scale responses.

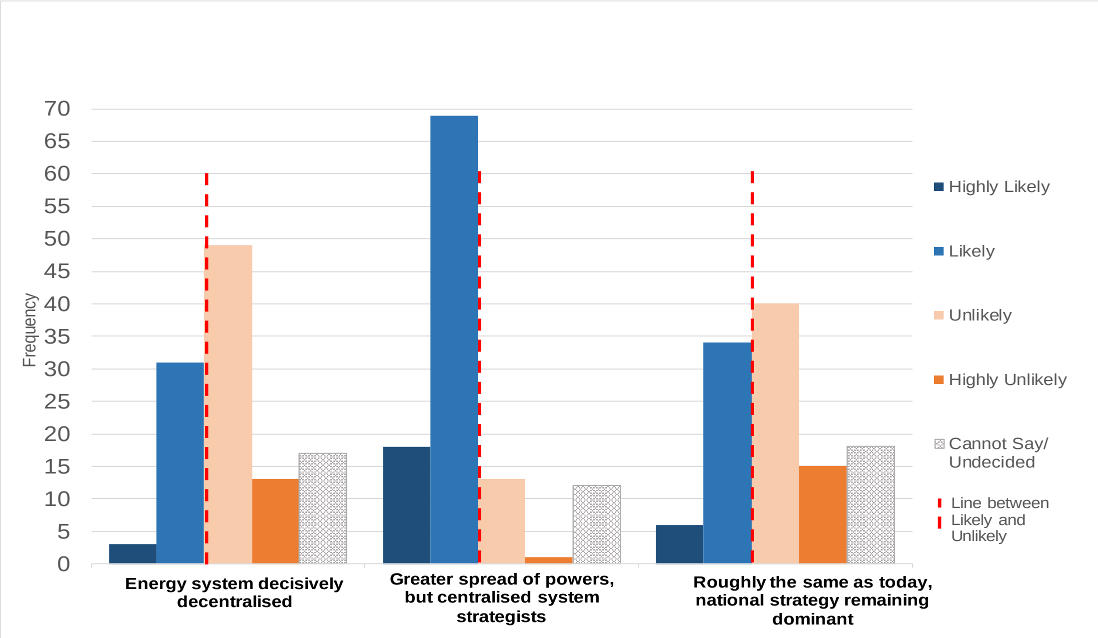
3.2 Energy System Governance

Survey participants were asked to assess three different propositions about future UK energy system governance:

1. *The UK state is moving decisively away from centralised control, with greater powers to nations, regions and cities. So by 2040, UK energy systems will reflect regional and local priorities above national strategy and operation*
2. *By 2040, there will be a greater spread of powers between national and local bodies, with planning and implementation devolved to local and regional authorities but with national government, regulators and system operators remaining as the main system strategists*
3. *The distribution of powers between national and local authorities in 2040 will largely resemble those of today, with national strategy and planning remaining dominant*

As shown in Figure 2, the survey sample considered the second proposition ('greater spread of powers') most likely; over three-quarters (77%) of all respondents saw this option as either likely or highly likely. This was more than double the number of respondents (35%) who saw the 'no significant change' proposition (option 3) as likely or highly likely. The 'decisively decentralised' proposition (option 1) was seen as the least likely – only 30% of respondents judged it likely or highly likely. Overall, this suggests most experts expect a moderate shift toward more local energy governance in the UK over the next 20 years.

Figure 2: Possible governance arrangements for the UK energy system in 2040



In their comments, several respondents noted that UK energy governance arrangements were already changing, with some powers being transferred to devolved governments, and some local authorities developing local energy strategies. However, participants disagreed on the significance (and merit) of these changes, and on how much further they would (and should) develop by 2040.

Those anticipating only a limited shift to decentralised governance noted the political sensitivities of energy policy and the perceived need to retain a coherent national strategy; others saw decentralised governance as undesirable and costly, given the suggested greater economies of scale and scope of centralised control:

'Some decisions can only be taken by national government … Politically I think it unlikely that central government will take a step back from energy.'

Official in a public body

'On a whole systems basis I can only see energy becoming more centralised not less … some of the big decisions we have to make will have to be made centrally.'

Senior industry consultant

'Economies of scale … mean that a fully decentralised system is unlikely unless affordability of energy ceases to be a goal.'

Senior academic mathematician

By contrast, others suggested that localised governance was a welcome and increasingly important *enabler* of the UK's energy transition:

'The low carbon transition … needs policy development on a more regional scale with more focus on the requirements of individual regions and communities.'

Mid-management industry specialist

'The state can no longer afford the inefficiencies of centralised control.'

Chair of an environmental NGO

Some respondents described a combination of technological, economic and political forces driving decentralisation, including digital technologies and the changing political ambitions and economic circumstances of local authorities.

> *'Provision of energy services provides a potential revenue stream and enables delivery of social objectives … local bodies will become more involved.'*

Senior Lecturer in engineering

> *'Distributed energy is very fashionable, regardless of whether it is the most cost-effective solution.'*

Mid-career economist in a public body

In Round 2, the vast majority of respondents (96%) either didn't respond to the invitation to reconsider their view, or expressed an unchanged view. Several respondents offered new comments without changing their Likert scale responses, but most of these didn't engage directly with others' views from Round 1. Only two respondents changed their Likert scale responses – both now favouring the majority view that a greater spread of powers was most likely.

3.3 Security and Flexibility Arrangements

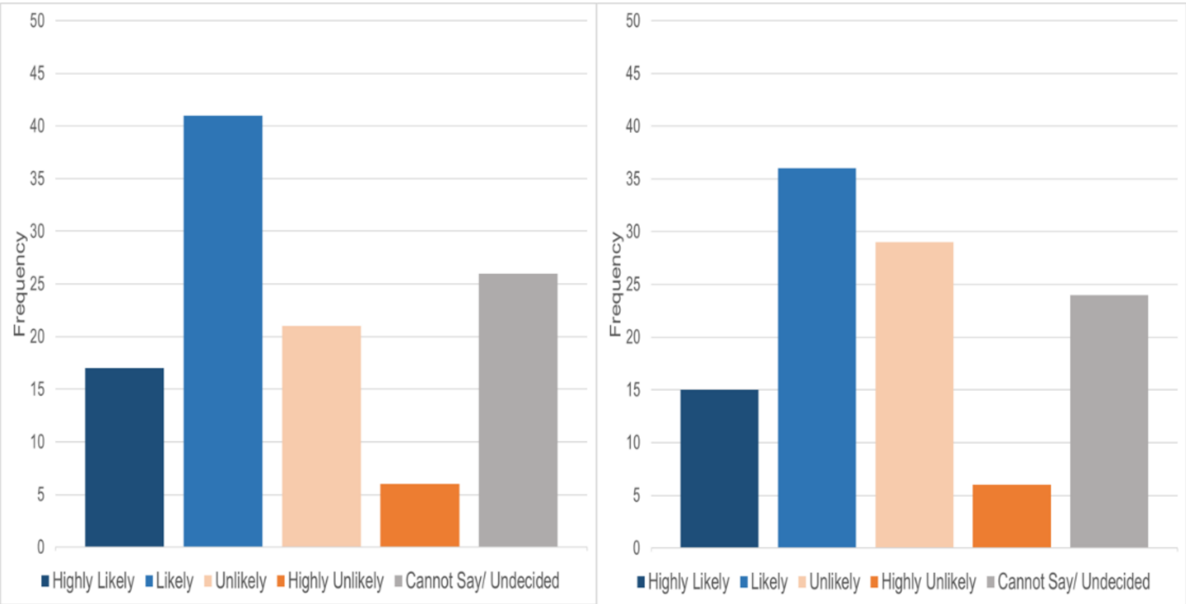
Participants were asked to assess a single proposition about UK energy system security and flexibility provision in 2040, for two different sectors:

- *UK energy system security and flexibility will rely more on local balancing and reserves than on international trade and national balancing (a) for heating in buildings, and (b) for power*

As Figure 3 shows, many respondents thought a greater reliance on local balancing and reserves was either likely or highly likely for both heating in buildings (52% of all responses) and power (46%); at the same time, there was a relatively high number of 'undecided or cannot say' responses to this question (23% of all responses for buildings' heating and 22% for power).

Figure 3: Energy security and flexibility in 2040: will local sources dominate?

(a) for heating in buildings (b) for power



Some respondents' comments highlighted the multiple factors at work in providing energy system flexibility and security – including policy choices on heat sector decarbonisation and electricity interconnectors – and were unable or unwilling to give a firm answer. Others argued that system security would be predominantly provided at the local scale by 2040:

> *'[Given] the emergence of smart systems and the general need to decarbonise … I would expect the national system to be supplementary to local flexibility.'*

Senior official in a public body

> *'The ability of smart [technology] to open up new demand response opportunities and the variable & inflexible nature of many new assets on the system should all create much stronger incentives for local balancing services than in the past.'*

Mid-management economist in a public body

By contrast, others argued that national infrastructure and international trading would continue to play a dominant role:

> *'interconnection is important to do the balancing … there is not enough local generation.'*

Senior academic engineer

> *'The majority of heating in 2040 is still likely to be from gas, the bulk of which will be imported.'*

Modelling analyst in a public sector body

There were varied views on whether heating or power was more likely to see a shift to localised balancing and security:

'Decarbonising heat may well involve more localised sources … for power, interconnectors are still likely to play an important role'

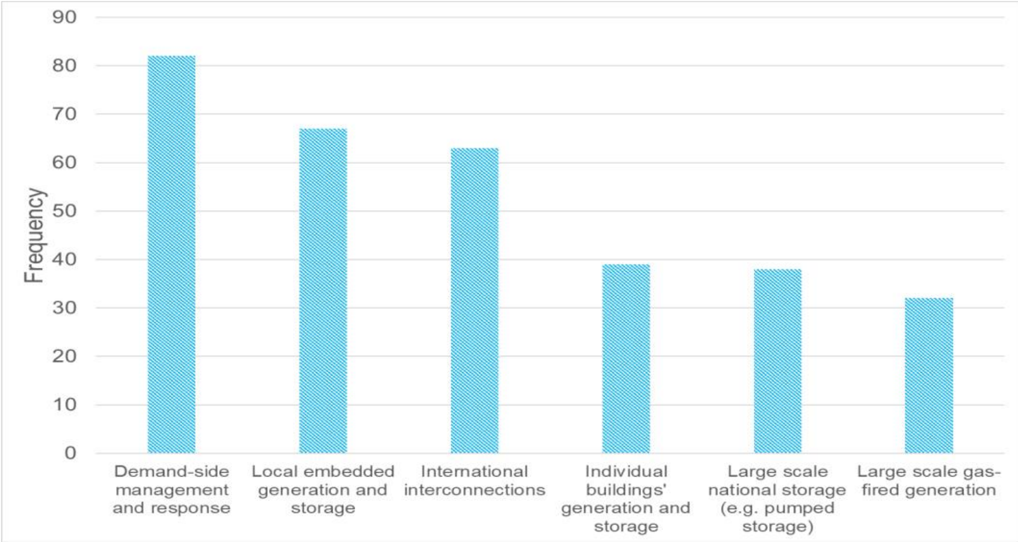
Mid-career advisor in a public body

'Power sector decarbonisation makes security and flexibility inherently a local issue, mostly relating to UK-based generation from indigenous resources.

Modelling analyst in a public sector body

Participants were also asked to identify the main sources of security and flexibility for the UK electricity system in 2040 from a given list (or alternatively offer their own suggestions). The results, shown in Figure 4, revealed high expectations about the future role of demand side management and response (DSM&R), with 82 votes; other sources seen as likely to play a were local generation and storage (with 67 votes) and international interconnectors (63 votes).

Figure 4: Main sources of security and flexibility in UK electricity supply in 2040



Some respondents were reluctant to choose between different sources of flexibility and security, and instead emphasised multi-scale provision, with the gradual emergence of more local sources. However, several comments anticipated a key future role for DSM&R and local storage:

> *'[The] business and technological case for large-scale storage seems weaker than digitally-enabled distributed storage and production.'*

Lecturer in social science

> *'EVs [electric vehicles], electrified heat … and distributed energy storage will result in huge flexibility resources being located on the local distribution networks.'*

Mid-management industry specialist

Others expressed caution about the likely contribution of DSM&R and local storage, and suggested that large scale sources of security and flexibility would continue to play an important role, especially for inter-seasonal response:

> *'I am not convinced of the potential for DSR to deliver the large volumes of balancing needed.'*
>
> Director in a public-private partnership

> *'Long term variations will require very large stores and interconnectors on large national/international scales'.*
>
> Professor of energy modelling

In Round 2, only 17% of participants changed their rankings of the main sources of flexibility for UK electricity supply in 2040; only a quarter of these (just three respondents) explicitly mentioned Round 1 results in explaining their changed view – two were persuaded to add DSM&R to their list and one added international interconnectors. Five others questioned or criticised Round 1 results while not changing their own view. Free text comments showed continuing disagreement about the impact of DSM&R: some saw them as unlikely to play a major role by 2040 because of long roll-out times, the need for consumer buy-in and their inability to offer inter-seasonal response. Others argued that some forms of DSM&R require very little consumer involvement and could play a key role by 2040.

3.4 Innovations for decarbonising power

Participants were asked to rank a range of social and technological innovations in terms of their contribution to UK electricity system decarbonisation from now to 2040, from a list of suggested options or by nominating others. As shown in Figure 5, large-scale renewables emerged as the highest ranked innovation, by some margin (with 82 votes); other highly ranked innovations included demand side management and response (DSM&R) (63 votes), digitalisation and smart grids (45 votes) and buildings scale microgeneration / prosumers (41 votes).

On large-scale renewables, respondents pointed to a strong track record of deployment and falling costs. One respondent identified the benefit of having a small number of centralised actors involved:

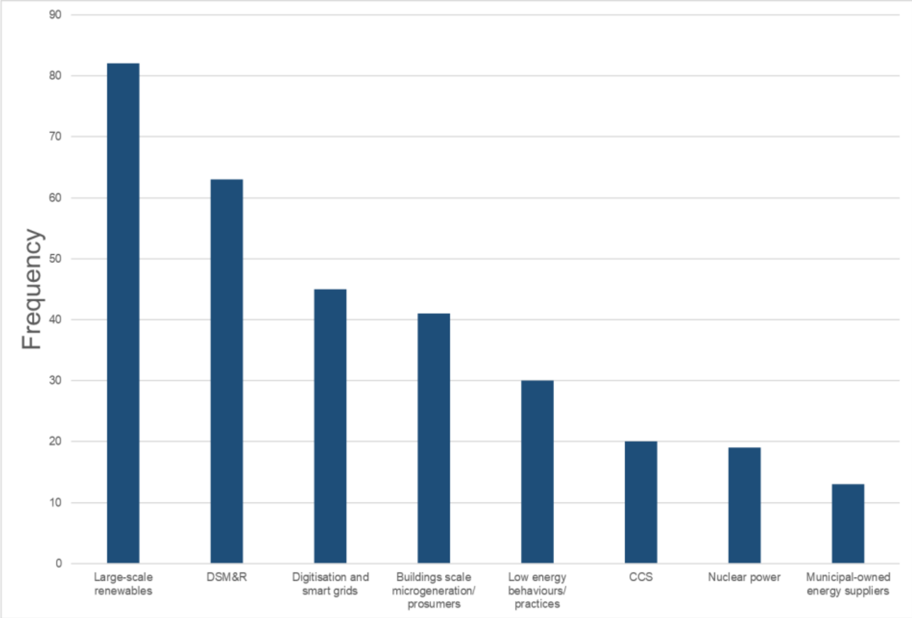
> *'Renewables have had a large impact … prices are still falling and installations increasing. While smart grids / demand response can help, I think these will be the secondary rather than primary contributors.'*

Senior academic interdisciplinary researcher

> *'Large scale renewables and smart grids are both areas that involve relatively few decision-makers – so I expect them to have significant carbon reduction impact.'*

Early-career academic social scientist

Figure 5: Innovations for decarbonising the UK's electricity system by 2040



Again, a number of participants highlighted cross-scale synergies, with DSM&R complementing large scale renewables deployment. Several comments drew unfavourable comparisons between large scale thermal generation technologies (CCS and nuclear power) and large-scale renewables coupled with demand side management. One respondent noted the ‘political will’ barrier facing some large scale technologies:

> *‘Nuclear power and CCS are moving too slowly, although I do worry that without them targets will not be reached.’*

Director in a public-private partnership

> *‘CCS and nuclear depend on political commitment in order to happen, this may crystallise in the long term, but the easier and cheaper things will happen first’*

Mid-career environment advisor in a public body

There were mixed views about the role of municipal energy – one respondent put it centre-stage, while others noted that local energy projects tended not to prioritise decarbonisation:

> *'A combination of municipal energy supplier and support for building-scale microgeneration would make the biggest contribution to decarbonising the electrical energy system.'*

Mid-management industry specialist

> *'Municipally-owner energy suppliers might be more prolific but they often have other goals aside from decarbonisation.'*

Mid-career academic engineer

In Round 2, 12 respondents changed their rankings (17% of the Round 1 sample) – none of whom made an explicit reference to Round 1 results. Eight of these either added-in DSM&R or promoted it in their rankings, although a senior engineer at a government body expressed concern that their large anticipated role among other respondents was "overly ambitious". Two others added-in digitalisation and smart grids, and an independent consultant acknowledged the doubts voiced about CCS but argued that there remained no alternative.

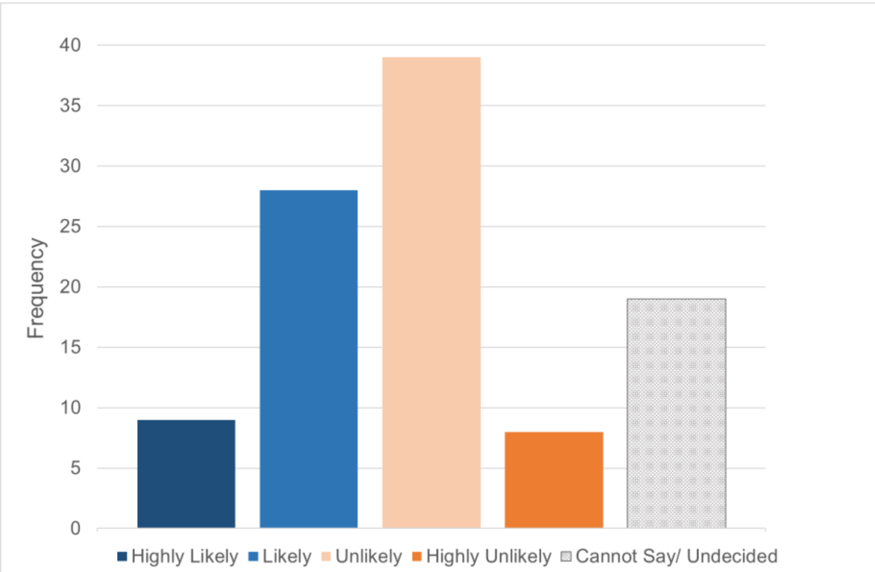
3.5 The future of large supply firms

Participants were asked to assess the likelihood of the following proposition:

- *By 2040, new intermediaries, aggregators and community energy companies will have largely replaced the dominance of the large utility firms supplying electricity in the UK*

The results, in Figure 6, show more respondents saw this proposition as *unlikely* or *highly unlikely* (46% of all respondents) than *likely* or *highly likely* (36%), while 18% of respondents were unwilling or unable to say.

Figure 6: The replacement of large utility firms supplying electricity by 2040



Several respondents argued that large supply firms would continue to exploit economies of scale, and exert significant market power and political influence:

> *'New business models will have a role to play, but I don't think they will replace the dominance of the large utility firms.'*

Senior official in a government body

'Economies of scale will dominate and most of the UK's electricity will continue be supplied by large companies … New ideas will likely be appropriated, absorbed, and repurposed by the existing players.'

Senior academic physical scientist

Some argued that disruption to large energy suppliers would be resisted because it would present a risk to system stability and security:

'This [proposition] is unlikely because there will need to [be] good coordination and regulation. The risk to the supply security is high.'

Professor of engineering

'Energy system stability at the national/international level requires large utility management'

Professor of energy modelling

Others noted that change was already happening and would accelerate as digital technologies opened up new business models and market opportunities:

'As soon as smart meters are prevalent, the value in the data will cause tech companies to flood into the market. The sticky customer pool will dwindle and become more of a hassle to the Big 6 as prices are capped.'

Senior official in a public body

Other respondents emphasised the more heterogeneous make-up of future supply, with a continuing, but reduced, role for large supplier firms:

'There will be large national providers … but not the current firms and not with the same dominance of the market.'

Senior regulation specialist in an energy company

'New providers will develop ways of fulfilling our needs for comfort etc. in combination with other services, rather than selling a commodity. Change is inevitable.'

Senior engineer at a government body

In Round 2, only 5 participants changed their answer (just 7% of the total Round 2 sample), only one of whom made explicit reference to Round 1 results. Of those changing 'sides' (i.e. shifting from likely to unlikely, or vice versa) two were persuaded that big energy suppliers would adapt, while one was convinced by the contrary argument:

'Agree with the majority. Big companies will adapt, and stay big. They've the necessary capital for innovation.'

Senior academic social scientist

'I now feel that … the incumbents will be usurped. They won't be able to adapt their monolithic business structures and organisations in time.'

Academic environmental economist

3.6 Policy priorities

Participants were asked for their views on the UK's energy policy priorities. The first question asked for an assessment of the importance of four high level policy drivers between now and 2040. While the majority of respondents saw all four policy drivers as either a 'high' or 'moderately high' priority, 'decarbonisation and a green economy' emerged as the highest priority (judged a 'high priority' by 76% respondents), followed by energy security (49%), affordability for customers (34%) and industrial strategy and local / regional economic growth (29%).

In Round 2, Only three respondents changed their Likert scale choices, only one of whom explicitly mentioned Round 1 results to justify their change – to criticise the relatively low ranking of affordability. Three others questioned or criticised others' views in Round 1, while maintaining their own view; comments here criticised the relatively low ranking of security, affordability and 'jobs' concerns, with one respondent suggesting that the 'downplaying' of affordability concerns was a result of 'academic bias'. (The results showed no statistically significant difference between academic and non-academic respondent groups on this issue).

Participants were then asked whether they agreed or disagreed with a list of more specific policy actions. Among these, 'Establishing energy demand reduction as a policy priority' emerged as the most popular action, with 62% strongly agreeing). Other proposals included 'supporting greater citizen involvement in regional and local planning for energy projects' (30% strongly agreeing), 'using competitive markets and auctions to support low carbon technologies' (26%), 'supporting and accelerating the transition towards distributed energy generation and storage' (21%) and 'facilitating a devolved and regionally-led approach to energy system change' (19%). In respondents' comments, there were some differences on whether policy should actively promote decentralisation and localisation:

> *'There is potential for significant devolved and regionally led delivery if it is appropriately facilitated.'*
>
> Director in a public-private partnership

> *'I am torn … about a regionally-led transition … there are pros and cons to this approach, and in some cases … it makes sense to focus on large-scale change'*
>
> Early-career academic social scientist

In Round 2, only two respondents changed their Likert scale answers on policy actions, with just one making explicit reference to Round 1 results. In both cases, these were to give a higher priority toward 'striving for energy independence and avoiding import-dependence'.

4 Summary and Discussion

4.1 Summary

Overall, the UK energy researchers and stakeholders surveyed here offer a mixed response to the 'smart and local energy revolution' proposition. A partial shift toward more local governance and infrastructure over the next two decades is seen as likely, but at the same time national governance and infrastructure are considered critical by many, and statistical analysis shows that the majority of participants do not accept the wholesale energy revolution proposition (see Appendix B). Qualitative data analysis suggests that this mixed response goes beyond assessments of likelihood: while many respondents recognise the gathering momentum behind the smart and local energy revolution proposition and express some support for policy measures associated with it, others question its merits and desirability.

In some areas respondents anticipate a significant trend to smart and local system operation. For example, a majority of experts expect more distributed energy system governance, and for energy security and flexibility to be mostly provided locally by 2040. There are also high expectations about the role of demand side management and response and local embedded generation and storage in the future power system, although others – including many domain specialists – question the system-wide significance of these developments. There is also widespread support for policy measures to promote distributed energy, but alongside other measures focussed on national or individual scales.

In other ways, respondents were cautious or questioning about the smart and local energy revolution proposition. On governance, most expected only limited redistribution of powers by 2040, with national organisations remaining key system strategists. On the future of large supplier firms, many thought it unlikely that large utilities would be wholly replaced by new organisations. In terms of overall policy goals, decarbonisation and the development of a green economy were seen by most as a higher priority than industrial strategy and local and regional economic growth.

Respondents' written comments help explain the mixed response to the smart and local energy revolution proposition. For example, the widely expected continuation of central governance reflected a view of the continuing political and strategic importance of energy –

but also, a view among some that localisation might undermine energy transition efforts by increasing costs or reducing transparency. Others see local energy governance as an important enabler of the transition, or consider that gathering local political interests will outweigh other concerns. Many respondents highlight the multi-scale interdependencies of energy systems.

Other comments note the uncertain dynamics of energy transition, including policy and strategy choices and outcomes. On the future incumbent firms, many respondents expect large suppliers to adapt to change and retain an important ongoing role in system co-ordination, while others extrapolated from emerging developments in supply business models to anticipate a much more disruptive future. There were also differing preferences about the scale dynamics of transitions: for some, large scale technologies and concentrated agency offer the best path for rapid change, but for others small scale technologies and distributed agency are more promising (see Wilson, 2018).

4.2 Explaining response patterns: the role of status, discipline and expertise

Responses to the vast majority of the survey questions and prompts covered here (84%) showed no statistically significant difference between academic and non-academic stakeholder groups (at the 95% confidence level). Even where a statistically significant difference was found, in most cases there was no difference in the majority view or the median value of Likert scale responses – differences tended to be in the strength of agreement or disagreement rather than across the agree-disagree divide. For example, on governance, almost half (49%) of academics consider that national strategy and planning will remain dominant in 2040, compared to only 27% of non-academics – suggesting academics are relatively continuity-led oriented on this question. On other issues, however, such as whether large scale national storage will play an important role in the UK electricity system in 2040 – a relatively continuity-based proposition – non-academics show greater support (80% of non-academics selected this option, compared to 61% of academics).

On preferred policy measures, although there was no statistically significant difference between academics and stakeholders on high-level policy drivers, some differences were seen in preferred policy measures, though again this tended to be in terms of the strength of support. In some cases, academics show stronger support for some relatively disruptive measures, such as assisting new entrants in the energy market (89% of academics agreed or strongly agreed with this measure, compared to 64% of non-academics) and facilitating a devolved approach to energy system change (supported by 89% of academics compared to 69% of non-academics). In other areas, however, there is little difference: over 90% of both groups agreed or strongly agree with measures to assist the digitalisation of energy systems, and over 85% of both groups agree or strongly agree with using competitive markets to promote low carbon technologies.

Respondents' disciplinary backgrounds are also largely insignificant in accounting for variations in response. Only one of the survey propositions in Section 3 shows a statistically significant difference by discipline (at the 95% confidence level), on 'establishing energy demand reduction as a policy priority'. Again, though, this was a difference of strength of support, and all disciplinary groups supported this proposition to some extent. Considering only ‘monodisciplinary’ respondents (many respondents identified themselves as having multiple disciplinary backgrounds), 87% of social scientists strongly agreed with this proposition, compared to only 43% of engineers.

There are also few significant differences of view according to levels of expertise. The only statistically significant difference between domain experts and other respondents (at the 95% confidence level) was on the main sources of UK electricity system flexibility in 2040 (Section 3.3, above). Here, respondents who self-identify as security and flexibility experts are more likely than other respondents to select large scale sources of security and flexibility: 75% of domain experts selected international interconnectors, compared to 46% of non-domain experts, while 39% of domain experts selected large scale gas-fired generation, compared to 23% of non-domain experts.

In their comments, domain experts noted the reliability and cost effectiveness of large scale security and flexibility technologies, and the need for such technologies to support the further diffusion of intermittent renewables. Security and flexibility experts are also less likely to support policy measures associated with the smart and local energy revolution (see section 3.6, above), including actions to support a devolved and regionally-led approach to energy system change (this was strongly agreed or agreed to by 88% of non-domain experts but only 62% of domain experts) and accelerating the transition towards distributed energy generation and storage (strongly agreed or agreed to by 93% of non-domain experts but only 59% of domain experts).

Although security and flexibility experts tend to react relatively cautiously to some aspects of the smart and local energy revolution proposition, this does not correspond to significant differences by discipline. Just over a quarter (27%) of all our respondents identify themselves as security and flexibility domain experts. Of these, 37% have multiple disciplinary affiliations and 30% offered no disciplinary affiliation – only 29% identify as either engineers or economists (and there is no statistically significant difference between the ‘engineers or economists’ group and other groups on this question). Overall, therefore, respondents’ orientations to disruptive or continuity-led transition and the smart and local energy revolution proposition are not decisively influenced by their differing levels of expertise, status as academics or non-academics, or disciplinary background.

Across the sample as a whole, individual respondents showed varied issue-specific orientations to the smart and local energy revolution proposition. These issue-specific orientations are durable, in that second round survey participants overwhelmingly reaffirmed rather than changed their views. However, looking across the multiple issues considered here, over three-quarters of respondents (79%) show neither a strongly disruptive nor strongly continuity-led overall orientation – 19% can be considered to have an overall orientation to disruptive change and 3% to continuity-led change (see Appendix B). This means that rather than having fixed overarching orientations to energy system dynamics, most experts consider the likelihood and desirability of disruption and continuity-led change on an issue-by-issue basis, going beyond uniform transition narratives.

4.3 Our findings in context

Only tentative comparisons can be made between our results and other surveys, given differences in research design and methods. For example, the Delphi Energy Future 2040 (DEF) findings (BDEW et al., 2016), although having similar broad aims and design to our survey, addressed international energy dynamics rather than country specific issues, and its respondents were mostly European-based (over half of all respondents were German-based), mostly drawn from the public sector, businesses and civil society groups (only 15 % were from the science and research sector).

Acknowledging these differences, some comparison is possible: for example, a majority (around 70%) of DEF respondents considered that decentralisation of energy systems was 'likely' or 'certain', with a strong envisaged role for municipalities and prosumers in distributed energy governance; large scale technologies such as CCS and nuclear power were seen as much less likely to play a significant role. Two-thirds of DEF survey respondents considered that traditional energy companies would be displaced by 2040, and over 90% thought power trading markets would be 'disintegrated' over the same period, particularly in Europe or North America. This suggests a stronger orientation towards a disruptive energy transition in the DEF survey than in our findings. Explaining this difference is not straightforward, but recognising that experts show a range of contextual biases (Burgman, 2015), it may reflect differences in energy transitions in Germany and the UK, with Germany pursuing a more local and decentralised path (Geels et al., 2016)

There are also some similarities and differences in the Energy Institute's annual Energy Barometer surveys and our survey (Energy Institute, 2019, et seq.), perhaps reflecting different response bases and survey designs (see 2.1, above). For example, there was a difference in 2019 Barometer respondents' overall policy priorities compared to our results, with energy security rather than decarbonisation ranked highest (Energy Institute, 2019). The most important emerging innovations over the next 10 years were grid-scale battery storage, demand-side response and small scale battery storage; expectations for nuclear power and CCS have declined over successive Barometer surveys (Energy Institute, 2019). While two thirds of 2017 Barometer respondents considered a shift to more decentralised business models as being highly likely, the UK national government – rather than devolved or local governments – was seen as the key governance body for the UK energy transition (Energy Institute, 2017). Overall, the Barometer's results, like ours, suggest that the UK energy transition will be shaped by a mix of disruptive and continuity based dynamics.

5 Conclusions and Implications

A smart and local energy revolution narrative has recently emerged in the UK and elsewhere, sitting alongside highly ambitious goals for decarbonisation. Understanding the significance of the energy revolution proposition in the context of the UK's energy transition goals was seen here as a challenge to interdisciplinary expertise, and the holistic analysis of change.

Our results suggest that while energy experts see smartness and localisation becoming more important over the next two decades, under a wave of digital and distributed innovations and a gathering local political imperative, they are not expected to dominate whole system change. Most researchers and stakeholders expect the UK energy transition to be shaped by repurposing alongside disruption, and by complementarities between new and established infrastructure and organisations, with large infrastructures and organisations likely to play key continuing roles. Suggestions of an imminent wholesale energy revolution were largely refuted.

This mixed response does not simply reflect a battle between old and new vested interests (‘incumbents versus new entrants’), as our survey respondents were mostly independent publicly funded research academic researchers. Instead, it appears to reflect some important uncertainties associated with the energy revolution proposition – for example, on the system-level significance of smart innovations in delivering the energy transition, but also, more subjective and indeterminate aspects, for example, on the merits and desirability of decentralised governance.

In more specific, bounded areas of disagreement, such as the impact of demand side management and response for whole system flexibility and security, additional evidence should help resolve expert differences, and support for demonstrations and evidence reviews is recommended in these areas. In more indeterminate and subjective areas, such as governance arrangements, the differences are unlikely to be reconciled through improved evidence, and the need here is for strong independent analytical capacity and more understanding of the values which inform expertise (Pielke, Jr, 2007; Li and Pye, 2018).

Following the call from Lagendijk and Van der Vleuten (2013) our results help ‘open-up' transition narratives. From a historically informed perspective, questioning the likelihood and desirability of an infrastructure revolution is unsurprising. As with earlier episodes of change, the smart and local energy revolution proposition is socially constructed, and political contestation and policy choice – as well as evidence – will determine the extent to which it is realised.

For whole systems research, our results reaffirm the value of allowing a variety of well-informed experts to transparently interrogate alternative futures. Philip Tetlock (2010, p.472) has described this as improving the "integrative complexity of public debate and serv[ing] as a break on polarization". Holistic interdisciplinary analysis is challenging, but it offers more robust policy guidance than uniform transition narratives.

Appendices

Appendix A: Non-academic survey respondents, by expert type and scenario orientation

Organisation Type	**Expert Type***	**Scenario Orientation****
Government department	Mandated	Neither
National executive agency	Mandated	Neither
National executive agency	Mandated	Neither
National executive agency	Mandated	Neither
National executive agency	Mandated	Neither
Government department	Mandated	Neither
City council	Mandated	Neither

National executive agency	Mandated	Neither
National executive agency	Mandated	Neither
National executive agency	Mandated	Neither
Energy regulator	Mandated	Neither
Parliamentary advisory body	Mandated	Neither
Parliamentary advisory body	Mandated	Neither
Government department	Mandated	Neither
National executive agency	Mandated	Neither
National executive agency	Mandated	Neither
Government department	Mandated	Neither
National innovation agency	Mandated	Neither
Energy system operator	Mandated	Neither
National innovation agency	Mandated	Neither
Energy system operator	Mandated	Neither
Nuclear regulator	Subjective	Continuity
Large energy company	Subjective	Continuity
Industry association	Subjective	Continuity
Large energy company	Subjective	Continuity
Large gas company	Subjective	Continuity

Industry association	Subjective	Continuity
Independent supply company	Subjective	Disruptive
Independent supply company	Subjective	Disruptive
Third sector organisation	Subjective	Neither
Independent consultant	Subjective	Neither
Independent consultant	Subjective	Neither
Independent consultant	Subjective	Neither
Independent consultant	Subjective	Neither
Independent consultancy	Subjective	Neither
Buildings consultancy	Subjective	Disruptive
Independent consultant	Subjective	Neither
Industry association	Subjective	Disruptive
Third sector organisation	Subjective	Neither
Third sector organisation	Subjective	Neither
Independent consultancy	Subjective	Neither
Third sector organisation	Subjective	Neither
Third sector organisation	Subjective	Neither
Independent think tank	Subjective	Disruptive
Third sector organisation	Subjective	Neither

Table A1: Non-academic survey respondents, by expert type and scenario orientation

*Based on Needham and de Loë's (1990) expert typology

** See Section 2.3, page 7.

Appendix B: Statistical Analysis of Whole Sample Orientation

In order to statistically analyse whether the survey sample as a whole showed an orientation to either continuity-led or disruptive change, a scoring system was devised, with each survey question or statement assigned a Disruption or Continuity ('D or C') score, ranging from +2 to – 2 – with +2 representing a 'highly disruptive' orientation, +1 'disruptive', 0 'neither disruptive nor continuity-led, -1 'continuity-led' and -2 as 'highly continuity-led'. The authors then assessed each survey question or statement against this metric according to the extent to which it is judged consistent with a disruptive or continuity-based transition narrative. The ratings for each question are listed in Table A1.

Table A2: Disruption or Continuity Ratings for Specific Survey Questions

Survey Topic	Specific Statement	D or C score for likely/highly likely (or selection, for innovations)	D or C score of unlikely / highly likely (or non-selection, for innovations)
System Governance	*Energy system decisively decentralised*	2	-2
	Greater spread of powers but central strategists	1	-1
	Roughly the same as today, national strategy dominant	-2	2

Security and Flexibility Arrangements	*Heat - will local sources dominate?*	2	-2
	Power - will local sources dominate?	2	-2
Main sources of security and flexibility for UK electricity system	*DSM&R (DSM)*	1	0
	Local embedded generation and storage	2	0
	International interconnections	-2	0
	Individual buildings' generation & storage	2	0
	Large scale national storage	-2	0
	Large scale gas-fired generation	-2	0
Innovations for decarbonising the UK's electricity system	*Large-scale renewables*	-2	0
	DSM&R	1	0
	Digitalisation and smart grids	2	0
	Buildings scale microgeneration / prosumers	2	0
	Low energy behaviours / practices	0	0
	CCS	-2	0
	Nuclear power	-2	0
	Municipal-owned energy suppliers	2	0
The future of large electricity suppliers	*New intermediaries, aggregators and community energy companies will have largely replaced the dominance of large utility firms*	2	-2

Of 127 Round 1 participants, 14 did not answer any of these questions; these participants were filtered out. Of the 113 valid responses, the frequency table (Table A2) and histogram (Figure A1) below show the distribution of participants' overall 'D or C' scores across all questions in this analysis. The range of possible 'D or C' scores is +23 (for maximum

disruption) and -23 (for maximum continuity-led change). Although there is a slight overall tendency to disruption, as the mean is +2.57 and the median is +3.00, statistical tests do not confirm that the distribution significantly differs from normal. For the Kolmogorov-Smirnov test, p =0.02, which is marginally significant at the 95% confidence level, but for the more powerful Shapiro-Wilk test, p= 0.83, which is not statistically significant. As the Shapiro-Wilk test is not significant, we cannot be confident that this sample deviates from a normal distribution.

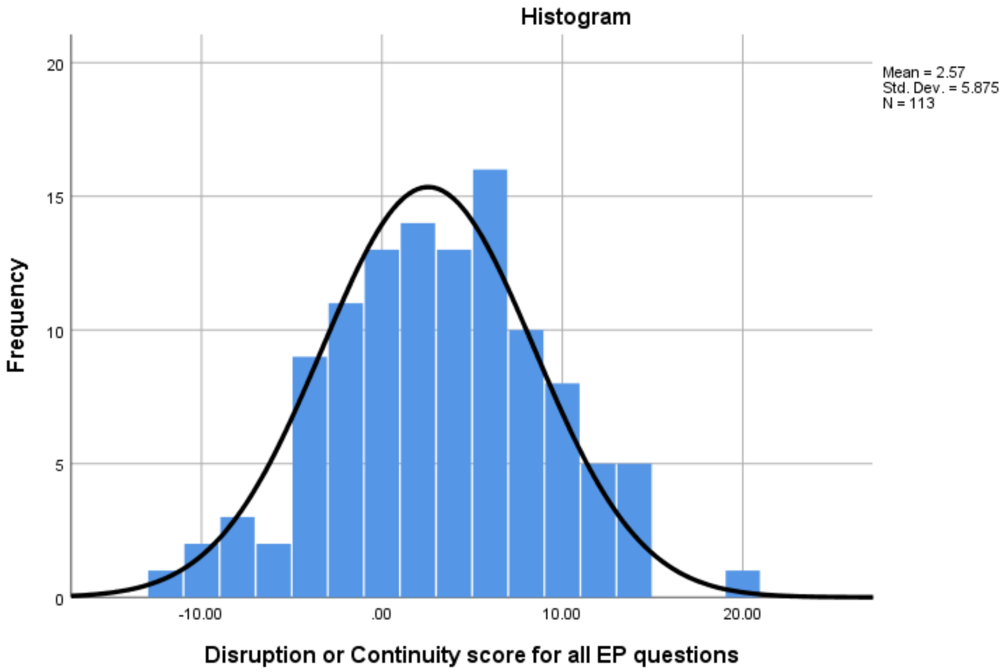
The distribution of individual respondent scores suggests that most experts do not expect disruption (or continuity) forces to dominate the UK energy system transition – most expect a combination of disruptive and continuity-led dynamics, with some areas seeing relatively disruptive change, and other areas more continuity-led change. Over three-quarters of all respondents (79%) score within a range of +11.5 to -11.5 (i.e. neither strongly disruptive nor strongly continuity-led), with 19% scoring over +11.5 (oriented to disruptive change) and 3% scoring less than -11.5 (oriented to continuity-led change.

Table A3: The distribution of participants' overall scores across all questions in the paper (n= 113)

		Frequency	Percent	Valid Percent	Cumulative Percent
D or C Score	-12.00	1	.9	.9	.9
	-10.00	2	1.8	1.8	2.7
	-8.00	3	2.7	2.7	5.3

	-6.00	2	1.8	1.8	7.1
	-5.00	5	4.4	4.4	11.5
	-4.00	4	3.5	3.5	15.0
	-3.00	6	5.3	5.3	20.4
	-2.00	5	4.4	4.4	24.8
	-1.00	6	5.3	5.3	30.1
	.00	7	6.2	6.2	36.3
	1.00	14	12.4	12.4	48.7
	3.00	8	7.1	7.1	55.8
	4.00	5	4.4	4.4	60.2
	5.00	10	8.8	8.8	69.0
	6.00	6	5.3	5.3	74.3
	7.00	7	6.2	6.2	80.5
	8.00	3	2.7	2.7	83.2
	9.00	5	4.4	4.4	87.6
	10.00	3	2.7	2.7	90.3
	11.00	4	3.5	3.5	93.8
	12.00	1	.9	.9	94.7
	13.00	4	3.5	3.5	98.2
	14.00	1	.9	.9	99.1
	19.00	1	.9	.9	100.0
	Total	113	100.0	100.0	

Figure A1: Distribution of individual respondents’ D or C scores for all questions in the paper



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References

Ahonen, T., Marttila, T., Dukeov, I. & Jalas, M. (2018) 'Understanding Smart Energy Transition: Insights to the Future Energy Technologies and Their Market Disruption in Finland.' *Futures of a Complex World: Proceedings of the Conference "Futures of a Complex World*, 12–13 June 2017, Turku, Finland. Available from: http://smartenergytransition.fi/fi/julkaisut/publications/ (last accessed on 31-07-19)

Arapostathis, S., Pearson, P. J. G. and Foxon, T. J. (2014) 'UK natural gas system integration in the making, 1960–2010: Complexity, transitional uncertainties and uncertain transitions.' *Environmental Innovation and Societal Transitions* 11: 87-102. https://doi.org/10.1016/j.eist.2014.01.004

BDEW (2015) *Delphi Energy Future 2040: Delphi-study on the future of energy systems in Germany, Europe and the world by the year 2040*, BDEW / GIZ / PwC. Available from: https://www.pwc.com/gx/en/industries/energy-utilities-resources/publications/delphi-energy-future-2040.html

BEIS (2019) 2017 *UK Greenhouse Gas Emissions, Final Figures*, UK Department for Business, Energy and Industrial Strategy / National Statistics. Available from: https://www.gov.uk/government/collections/final-uk-greenhouse-gas-emissions-national-statistics (last accessed on 15-08-19)

Bolger, F., Wright, G. (2011) 'Improving the Delphi process: Lessons from social psychological research'. *Technological Forecasting and Social Change* 78, 1500-1513. https://doi.org/10.1016/j.techfore.2011.07.007

Braunholtz-Speight, T., McLachlan, C., Mander, S., Cairns, I., Hannon, M., Hardy, J., Manderson, E. and Sharmina, M. (2019) *Visions for the future of community energy in the UK: realising the potential*, UK Energy Research Centre, London. Available from: http://www.ukerc.ac.uk/publications/visions-for-the-future-of-community-energy.html (last accessed on 31-07-19)

Brisbois, M.C. (2019) 'Powershifts: A framework for assessing the growing impact of decentralized ownership of energy transitions on political decision-making'. *Energy Research & Social Science* 50, 151-161. https://doi.org/10.1016/j.erss.2018.12.003

Burgman, M. (2015). Trusting Judgements: How to Get the Best out of Experts. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781316282472

Clark G. (2018) *After the trilemma – 4 principles for the power sector*, Speech by UK Business Secretary Greg Clark on the future of the energy market, 15th November 2018. Available from: https://www.gov.uk/government/speeches/after-the-trilemma-4-principles-for-the-power-sector (last accessed on 29-07-19)

Dayé, C. (2018) 'How to train your oracle: The Delphi method and its turbulent youth in operations research and the policy sciences.' *Social Studies of Science* 48(6): 846-868. https://doi.org/10.1177/0306312718798497

DECC (2011) *Overarching National Policy Statement for Energy (EN-1)* (London: The Stationery Office). Available from https://www.gov.uk/government/publications/national-policy-statements-for-energy-infrastructure (last accessed on 29-07-19)

de Loë, R. C. (1995) 'Exploring complex policy questions using the policy Delphi: A multi-round, interactive survey method.' *Applied Geography*, 15(1), 53–68. https://doi.org/10.1016/0143-6228(95)91062-3

de Loë, R. C., Melnychuk, N., Murray, D., & Plummer, R. (2016). Advancing the State of Policy Delphi Practice: A Systematic Review Evaluating Methodological Evolution, Innovation, and Opportunities. *Technological Forecasting and Social Change*, 104, 78–88. https://doi.org/10.1016/J.TECHFORE.2015.12.009

Devaney, L., Henchion, M. (2018). 'Who is a Delphi 'expert'? Reflections on a bioeconomy expert selection procedure from Ireland'. *Futures* 99, 45-55. https://doi.org/10.1016/j.futures.2018.03.017

Edwards, P. N. (2003) 'Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems' in Thomas J. Misa, Philip Brey, and Andrew Feenberg, eds., *Modernity and Technology* (Cambridge, MA: MIT Press, 2003), 185-225

Edgerton, D. (2010). Innovation, Technology, or History: What is the Historiography of Technology About? *Technology and Culture*, 51(3), 680-697. https://doi.org/10.1353/tech.2010.0007

Egyedi T. M. and Mehos, D. C. (eds.) (2012) *Inverse Infrastructures: Disrupting Networks from Below*, Edward Elgar, Cheltenham and Northampton, MA. https://doi.org/10.4337/9781781952290

Energy Institute (2017) *Views from UK energy professionals: Energy Barometer 2017*. Energy Institute, London. Available from https://www.energyinst.org/exploring-energy/resources/barometer (last accessed 31-05-20)

Energy Institute (2018) *Views from UK energy professionals: Energy Barometer 2018*. Energy Institute, London. Available from https://www.energyinst.org/exploring-energy/resources/barometer (last accessed 31-05-20)

Energy Institute (2019) *Views from UK energy professionals: Energy Barometer 2019*. Energy Institute, London. Available from https://www.energyinst.org/exploring-energy/resources/barometer (last accessed 31-05-20)

EPA (2009) *Expert Elicitation Task Force White Paper*, U.S. Environmental Protection Agency Washington DC. Available from [pdf]: http://www.chesapeake.org/stac/presentations/285_EPA%20Expert%20Elicitation%20White%20Paper%20Final%202011.pdf (last accessed on 31-07-19)

Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., Wassermann, S. (2016) 'The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014)' *Research Policy* 45, 896-913.

Grafakos, S., Flamos, A. (2017) 'Assessing low-carbon energy technologies against sustainability and resilience criteria: results of a European experts survey'. *International Journal of Sustainable Energy* 36, 502-516. https://doi.org/10.1080/14786451.2015.1047371

Grisham, T. (2009) 'The Delphi technique: a method for testing complex and multifaceted topics'. *International Journal of Managing Projects in Business* 2, 112-130. https://doi.org/10.1108/17538370910930545

Hall, S. and Roelich, K. (2015) *Local Electricity Supply: opportunities, archetypes and outcomes*, iBuild Working Paper, University of Leeds, Leeds. Available from: https://research.ncl.ac.uk/ibuild/outputs/reports/local_electricity_supply_report_WEB.pdf (last accessed on 31-07-19)

Hannah, L. (1979) *Electricity Before Nationalisation: A Study of the Development of the Electricity Supply Industry in Britain to 1948*, London, MacMillan/The Electricity Council.

Hommels, A. M., Hogselius, P., Kaijser, A., and van der Vleuten, E. (2013) 'Europe's Infrastructure Vulnerabilities: Comparisons and Connections'. In P. Hogselius, A. Hommels, A. Kaijser, & E. Vleuten, van der (Eds.), *The Making of Europe's Critical Infrastructure. Common Connections and Shared Vulnerabilities* (pp. 263-277). London, Palgrave Macmillan. https://doi.org/10.1057/9781137358738_10

HMG (2017) *Industrial Strategy: Building a Britain fit for the future*, UK Government Industrial Strategy White Paper, November 2017. Available from: https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future (last accessed 29-07-19).

Hughes, T. (1983) *Networks of Power: Electrification in Western Society 1880-1930*. Baltimore MD: John Hopkins University Press.

Jackson, S. J., Edwards, P. N., Bowker, G. C. and Knobel, C. P. (2007) 'Understanding Infrastructure: History, Heuristics, and Cyberinfrastructure Policy', *First Monday*, Vol. 12, No.6. Available from: https://firstmonday.org/ojs/index.php/fm/article/view/1904/1786 (last accessed on 31-07-19)

Jalas, M., Rask, M., Marttila, T., Ahonen, T. (2019) 'Strategic Research as a Mode of Academic Engagement: Assembling Smart Energy Futures for Finland'. *Science & Technology Studies* 32, 44-61. https://doi.org/10.23987/sts.65948

Johnstone, P., Rogge, K.S., Kivimaa, P., Fratini, C.F., Primmer, E., Stirling, A. (2020) 'Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom'. *Energy Research & Social Science* 59, 101287. https://doi.org/10.1016/j.erss.2019.101287

Lagendijk V., van der Vleuten E. (2013) 'Inventing Electrical Europe: Interdependencies, Borders, Vulnerabilities.' In: Högselius P., Hommels A., Kaijser A., van der Vleuten E. (eds) *The Making of Europe's Critical Infrastructure*. London, Palgrave Macmillan. https://doi.org/10.1057/9781137358738_3

Li, F. G. N. and S. Pye (2018) 'Uncertainty, politics, and technology: Expert perceptions on energy transitions in the United Kingdom'. *Energy Research & Social Science* 37: 122-132. https://doi.org/10.1016/j.erss.2017.10.003

Lindberg, M.B., Markard, J., Andersen, A.D. (2019). 'Policies, actors and sustainability transition pathways: A study of the EU's energy policy mix'. *Research Policy* 48, 103668. https://doi.org/10.1016/j.respol.2018.09.003

Linstone, H. A. and M. Turoff (2011). 'Delphi: A brief look backward and forward.' *Technological Forecasting and Social Change* 78(9): 1712-1719. https://doi.org/10.1016/j.techfore.2010.09.011

Makkonen, M., Hujala, T., Uusivuori, J. (2016) 'Policy experts' propensity to change their opinion along Delphi rounds'. *Technological Forecasting and Social Change* 109, 61-68. https://doi.org/10.1016/j.techfore.2016.05.020

McDowall, W., Eames, M. (2006) 'Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature'. *Energy Policy* 34, 1236-1250. https://doi.org/10.1016/j.enpol.2005.12.006

McKenna, R. (2017) 'The double-edged sword of decentralized energy autonomy' *Energy Policy* 113: 747-750. https://doi.org/10.1016/j.enpol.2017.11.033

Miles, I., Saritas, O., & Sokolov, A. (2016) 'Intelligence: Delphi' in Miles, I., Saritas, O., & Sokolov, A. *Foresight for Science, Technology and Innovation*. Springer International Publishing, Switzerland. https://doi.org/10.1007/978-3-319-32574-3

Morgan, M. G. (2014) 'Use (and abuse) of expert elicitation in support of decision making for public policy.' *Proceedings of the National Academy of Sciences* 111(20): 7176-7184. https://doi.org/10.1073/pnas.1319946111

New, P. (2016) 'The whole energy system is facing radical change', an Innovate UK blogpost by the Philip New, CEO of the Energy Systems Catapult. Available from: https://innovateuk.blog.gov.uk/2016/05/06/the-whole-energy-system-is-facing-radical-change/ (last accessed 29-07-19).

Needham, R.D., de Loë, R.C., 1990. 'The Policy Delphi: Purpose, Structure, and Application'. The *Canadian Geographer* 34, 133-142. https://doi-org.ezproxy.is.ed.ac.uk/10.1111/j.1541-0064.1990.tb01258.x

Nowack, M., Endrikat, J., Guenther, E. (2011) 'Review of Delphi-based scenario studies: Quality and design considerations'. *Technological Forecasting and Social Change* 78, 1603-1615. https://doi.org/10.1016/j.techfore.2011.03.006

PwC (2016) Capturing value from disruption: Technology and innovation in an era of energy transformation. PwC Global Power & Utilities. Available from: https://www.pwc.com/gx/en/industries/energy-utilities-resources/publications/capturing-value-from-disruption.html (last accessed 22-05-20).

Pielke, R. Jr. (2007) *The Honest Broker.* Cambridge: Cambridge University Press.

PwC (2018) Disruption on a global scale: What makes the next ten years the decade of disruption? PwC Canada. Available from: https://www.pwc.com/ca/en/industries/energy/energy-visions-2018/energy-visions-summary-2018.html (last accessed 22-05-20).

Schiølin, K. (2019) 'Revolutionary dreams: Future essentialism and the sociotechnical imaginary of the fourth industrial revolution in Denmark'. *Social Studies of Science,* August 2019. https://doi.org/10.1177/0306312719867768

Scottish Government (2017) *Scottish Energy Strategy: The Future of Energy in Scotland*, Scottish Government, Edinburgh. Available from: https://www.gov.scot/publications/scottish-energy-strategy-future-energy-scotland-9781788515276/pages/4/

Small, M., 2011. How to conduct a mixed methods study: recent trends in a rapidly growing literature. Annual Review of Sociology. 37 (1), 57–86. https://doi.org/10.1146/annurev.soc.012809.102657

Tetlock, P. E. (2005) *Expert Political Judgment: how good is it? How can we know?* Princeton, N.J. Oxford, Princeton, N.J., Princeton University Press.

Tetlock, P. E. (2010) 'Second thoughts about Expert Political Judgment: reply to the symposium', *Critical Review*, 22:4, 467-488. https://doi.org/10.1080/08913811.2010.542634

Turoff, M. (1970) 'The design of a policy Delphi' *Technological Forecasting and Social Change* 2(2): 149-171. https://doi.org/10.1016/0040-1625(70)90161-7

Trutnevyte, E., McDowall, W., Tomei, J. and Keppo, I. (2016) 'Energy scenario choices: Insights from a retrospective review of UK energy futures.' *Renewable and Sustainable Energy Reviews* 55: 326-337. https://doi.org/10.1016/j.rser.2015.10.067

UK Parliament (2017) *Industrial Strategy: First Review*, House of Commons Business, Energy and Industrial Strategy Committee, London. Available from:

https://www.parliament.uk/business/committees/committees-a-z/commons-select/business-energy-industrial-strategy/news-parliament-2015/industrial-strategy-report-published-16-17/ (last accessed on 31-07-19)

UKRI (n.d.) *Prospering from the energy revolution*, UK Research and Innovation website, available at: https://www.ukri.org/innovation/industrial-strategy-challenge-fund/prospering-from-the-energy-revolution/

Van der Vleuten, E., Högselius, P., Hommels, A. and Kaijser, A. (2013) 'Europe's Critical Infrastructure and its vulnerabilities: Promises, Problems, Paradoxes' in Högselius, P., Hommels, A., Kaijser, A. & Van der Vleuten, E. (eds.). *The Making of Europe's Critical Infrastructure: Common Connections and Shared Vulnerabilities*. Basingstoke and New York: Palgrave Macmillan, pp3-19. https://doi.org/10.1057/9781137358738_1

Weijers. T (2012) 'Centralisation and Decentralisation: A history of Local Radio and TV Distribution' in Egyedi T. M. and Mehos, D. C. (eds.) *Inverse Infrastructures: Disrupting Networks from Below*, Edward Elgar, Cheltenham and Northampton, MA. https://doi.org/10.4337/9781781952290.00012

Wilson, C. (2018) 'Disruptive low-carbon innovations' *Energy Research & Social Science* 37: 216-223. https://doi.org/10.1016/j.erss.2017.10.053

Wilson, C. and Tyfield, D. (2018) 'Critical perspectives on disruptive innovation and energy transformation'. *Energy Research & Social Science* 37, 211-215. https://doi.org/10.1016/j.erss.2017.10.032

Winkler, J., Moser, R. (2016) 'Biases in future-oriented Delphi studies: A cognitive perspective'. *Technological Forecasting and Social Change* 105, 63-76. https://doi.org/10.1016/j.techfore.2016.01.021