The future is flexible? Exploring expert visions of energy system decarbonisation

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Abstract
Decarbonising the energy system means moving from a centralised, fossil fuel-dependent one to one based primarily on renewable energy. Visions of whole system change focus on socio-technical concepts like electrification and flexibility, rather than single technologies such as nuclear or solar. The role that technological niches might play in relation to such systemic socio-technical visions is under-researched. Traditionally, technological niches are thought to nurture new 'proto-regimes', supported by coherent visions of how technologies will help solve problems within existing socio-technical regimes. However, the relationship between socio-technical visions like flexibility and individual demonstrator projects is more complex. Interviews with experts from the FLEXIS energy systems project (south Wales, UK) show how future visions associated with a range of demonstrator projects are being developed against the backdrop of a system-level vision of a flexible, multi-vector energy system. Interview data also shows how the development of visions for demonstrators draws on social learning about place and societal values overlooked in systemic visions. Such social learning can incorporate critical reflection on key assumptions that underlie dominant system-level visions. The extent such learning is possible through the development of potential niches, however, is subject to limitations that invite further research.

Keywords
Demonstrator projects, energy systems, energy transition, energy values, future imaginaries, sociotechnical imaginaries.

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Introduction

Decarbonising the energy system will require complex transformations in the dominant *socio-technical regime* (Geels, 2005), which is widely expected to involve moving away from a 'one-to-many' regime based on centralised fossil fuel generation to an increasingly decentralised 'many-to-many' system based on intermittent renewable energy (RE) generation (Bakke, 2016). Understanding how the interdependent social and technical elements of such a radically transformed system will need to change presents significant challenges (Verbong and Geels 2007). Visions of what a transformed future system might look like have, in recent years, begun to centre on the concept of 'flexibility', which has increasingly become a dominant concept across different national jurisdictions (e.g. National Grid 2013). Because the transition away from a centralised, fossil-fuel based system will involve wholesale changes to the economic relationships and regulatory frameworks built into the energy system, such visions are more complex than the kinds of single technology-focused visions often studied by science and technology studies (STS) researchers. These represent examples of what have been called 'heroic' visions (Janda & Topouzzi 2015), in which a specific technology (such as nuclear or solar power generation) plays the role of protagonist in a future-focused, deterministic narrative of wholesale socio-technical transformation. Visions of energy system flexibility are more complex, implying not only transformations in social practices, economic relations, and regulatory systems, but also integration of a variety of energy vectors and forms of production.

Such complex visions share some features with simpler, heroic visions, however. Technological niches are expected to play an important role in establishing credibility for visions of the future of energy. These niches represent experiments not only with new technologies but also with the interdependencies between different elements of a remodelled energy system (Smith, 2007). Research in STS has suggested that the likelihood of such niches exerting a transformative effect is increased if the development of niches is accompanied by strong and compelling future visions (Smith & Raven, 2012), which detail how they are likely to drive progress within the broader energy system, typically at national scale (Jasanoff and Kim 2009) towards a desired future (Bakker, et al., 2012). Such alignment between demonstrators and visions for national-scale system transformation creates credibility for demonstrators. Researchers in the sociology of expectations have shown how credible visions can exert performative effects in the present by helping create collaborative networks of researchers and supporting bids for resources (Borup, et al, 2006).

However, STS research has also suggested that energy experiments can attract credibility in some circumstances if they are supported by visions that actually diverge significantly from national system visions (Levenda et al 2019). This may be a side-effect of how some dominant future visions of system transition are translated in a top-down manner into a variety of heterogeneous contexts, as has been documented in visions of the electrification of energy systems imported through development governance mechanisms from the global North to the South (Cloke et al 2017). Where this happens, visions developed in one context may obscure or override alternative perspectives on how a system should be transformed in response to local needs. Resistance to demonstrator projects may then lead to critique of blindspots within the imported visions attached to them, perhaps leading to produce alternative, divergent local visions of energy system change. Typically, the possibility of social learning of this kind is seen as an effect of the inclusion of non-experts (generally including those without specialised expertise connected to the technical aspects of a demonstrator, and especially members of the public) in the assessment of proposed demonstrator projects and the visions attached to them (Tidwell & Tidwell 2018). However, such perspectives tend to enforce a dichotomy between expert and non-expert knowledge, in which experts with specialist knowledge relevant to the technical aspects of demonstrators are seen as bearers of dominant visions imposed on communities that host demonstrators, whereas non-experts may be privileged as wielders of critical reflexivity (i.e. being capable of reflecting on the assumptions and presuppositions that underlie such visions). Expert perspectives, however – and especially where future visions are concerned – cannot be treated so monolithically, given the 'possibility of disagreement and contradiction' within expert perspectives (Irwin et al., 1999, p. 1312).

In this paper, we examine one central question: issues of credibility affect the development of broader or system-level future visions of energy systems – but how does the local social and geographical context of demonstrator projects shape how experts understand credibility? We provide a literature review which focuses on STS research on the role of visions and criteria for their credibility in socio-technical change, and look at how visions for system-level decarbonisation have emerged in recent decades. Using data from expert interviews undertaken as part of the Flexible Integrated Energy Systems (FLEXIS) project in Wales, we show how experts interrogate central assumptions underlying dominant visions of flexibility as a result of their work in developing visions for local demonstrators. This, we show, includes questioning the ways in which decarbonisation may require the transformation of grid infrastructure, as well as examining the relative importance of different 'energy values' - 'the sometimes contested public values and expectations related to energy systems and their transformations in a given context' (Levenda et al 2019, 182). We also show how place is an important influence on how experts construct visions for specific demonstrator projects, and therefore on how they interpret the meaning of flexibility at the level of the national energy system. We close with reflections on these findings and their implications for further research.

Analytical perspective

Visions, technological niches and energy demonstrator projects

The sociology of expectations has shown how visions of socio-technical futures can have real, performative effects in the present (Skjølsvold, 2014). They can function as socio-technical 'future imaginaries' that reflect social and political discourses dominant in particular nation states and describe 'attainable futures and prescribe futures that the state believe ought to be attained' (Jasanoff & Kim, 2009, p. 120). Their role in relation to energy systems has been explored at scales ranging from localities (such as villages, towns and cities), across geographical regions, to national level, and chiefly in relation to specific technologies (Ballo, 2015; Kuchler, 2014). They describe desired future states, derived from values that circulate within shared discourses – such as convenience, affordability or sustainability. In the UK, for example, since the 1980s dominant visions of the energy system have been shaped by discourses of privatisation, in which energy is treated primarily as a tradable commodity, and cost efficiency in providing supply to meet predicted demand is the main value on which policy goals are based (Kern et al., 2014).

The real effects of visions in the present are theorised to be, in part, a consequence of their possessing credibility. Credible visions may be ones which provide plausible and convincing narratives about how to improve on the present (Bakker, et al., 2012), either through radical or incremental change. Often, imagined futures focus on how a new technology could resolve deep tensions within an existing socio-technical regime (Smith & Raven, 2012, 1032-33). STS research also shows that visions often gain credibility because they reflect problem definitions which are part of historically-dominant discourses, and thus implicitly privilege certain kinds of desired solutions, and tools for achieving them, at the expense of others. Visions or imaginaries are therefore anything but neutral. For example, researchers have shown how the visions of electrified energy systems, originating in the global North, have been translated to quite different contexts in the global South via specific demonstration projects that act as carriers of pre-made visions (Cloke et al 2017). Similar dynamics have been mapped elsewhere, such as in rural Wales (Cowell et al., 2011).

The role of demonstrator projects in propagating visions is important. A demonstrator project is a more or less geographically self-contained, small-scale investment designed to prove the viability of a particular approach to solving a problem. Such projects can serve as a means of translating (Rydin, 2013) visions between different contexts, then this implies they may also help to propagate dominant values, accepted problems and recommended solutions between heterogeneous contexts too. This is in addition to the role more widely ascribed within STS to demonstrators as examples of technological niches. Niches have been theorised as potentially creating wider transformations (Naber, et al., 2017) within dominant socio-technical regimes (Geels 2005), a perspective widely echoed in energy policy reports that position demonstrator projects as testing the viability and plausibility of strategic future visions for decarbonisation (CCC, 2016). Demonstrators do not, then, necessarily *only* translate visions from one context to another. They can also test the credibility of visions.

As well as testing new technologies, demonstrators are often experiments in a wider socio-technical sense, given that they may involve new business models, test new forms of regulation and reshape social practices (Vergragt, 2005). As a result, demonstrators can induce wider reflection on national visions and their implications, as well as also directly reflect*ing* them. While visions can help performatively establish demonstrators as 'proto-regimes' by lending them credibility (Smith & Raven, 2012), demonstrators can, on the other hand, help establish the credibility or otherwise of visions. Cloke et al (2017) show how such testing of credibility may occur through processes that involve non-expert actors (such as members of the public) in 'informal technology assessment' (Pesch et al. 2017), such as protest and other forms of resistance to local demonstrators and to the top-down visions which they are perceived to embody. Other researchers have documented how greater credibility for demonstrators can arise if the visons which accompany them are developed in ways that are attentive and responsive early on to local concerns. Over time, this may also lead to the production of regional or localised visions which diverge from dominant, national-scale visions (Levenda et al., 2019). Opening up visions of energy system change to input from non-expert voices is often seen as important more generally, given the dominance in debates over the future of energy of techno-economic expert perspectives (Grunwald, 2011).

Dominant visions: electrification

An example of how national-scale visions for energy system change can be translated via demonstrator projects into a variety of heterogeneous contexts is that of electrification. The concept of electrification as an integrative solution across the power, heating and transport sectors has been influential at various times and in different jurisdictions since its emergence in the USA at the end of the 19th century (Hughes, 1993). Its translation from North to South has most recently been undertaken via development agency-sponsored hydroelectricity projects that have acted as centres of gravity for the wholesale remodelling of energy economies in some developing countries along low-carbon trajectories (Smits & Bush, 2010). Visions of electrification are not, unlike the idea of an 'atomic future', necessarily based around a single 'heroic' (Janda and Topouzzi 2015) technology. Instead, they incorporate a variety of technologies, as well as other elements of dominant regimes, including beliefs about the inevitability of increasing energy demand (Shove 2003) and about appropriate regulatory/ownership structures, such as privatisation of energy systems taken from jurisdictions such as the USA, UK and EU and the priority of decarbonisation.

Visions of electrification developed over the last three decades in the UK, for example, have linked decarbonisation to 'green growth' (Ekins, 2002). Work on building credibility for such whole-system visions focused on how electrification might resolve deep tensions within existing energy regimes between the three poles of the 'energy trilemma': sustainability (mitigating anthropogenic climate change), concerns about scarcity and geopolitics (the value of energy security), and the growing costs of energy in privatised energy systems (the value of affordability). Concerns about climate change and energy security had begun to complicate the emphasis in energy policy on promoting the cost efficiency of infrastructure delivery, leading to wide public debate about the basis and direction of UK energy policy (Kern et al., 2014). By rapidly developing onshore wind farms and combined heat and power (CHP) technological niches to scale up renewable electricity production, it was expected that these system visions would become more credible (Hofman, 2005), which took on particularly optimistic form in industry, depicting the UK's future as the 'Saudi Arabia of wind energy' (Boyle, 2006).

Such national-scale visions of electrification were reflected in UK government energy policy scenarios from 2008 on (Winskel, 2016, p. 81), influenced also by the European Commission's Renewable Energy Directive (ECRED) of 2009. Their performative effects in the present were felt in the 'streamlining' of the planning system to prioritise developing installations held to be of 'strategic national importance' such as increasing numbers of onshore windfarms (Cowell & Owens, 2006). This focus on electrification was reflected in the proportion of demonstrator projects (72%) funded through public funds, industry or other sources in the period 2008 – 2018 which focused on the power system or electrification of heat and/or transport (Flett et al., 2018).

Visions of wholesale electrification, however, ran into significant challenges for various reasons, which have ultimately undermined the credibility of these visions and led to more differentiated visions of future energy systems (e.g. CCC 2016). Demonstrator projects were encouraged, in the UK as in other EU countries, to connect to national transmission grids before these grids were adapted to the needs of an energy system featuring increasing amounts of intermittent, distributed RE (e.g. O'Keeffe & Haggett, 2012). An emphasis on rapidly increasing the amount of RE production exposed other tensions within the existing regime. System-level modelling began to register the high cost of dealing with such system stresses and providing battery-based storage (Speirs et al., 2010), raising questions about the credibility of national-scale electrification of power and heat. Finally, the role of private industry in developing wind energy demonstration projects became linked to questions about whether these projects were effectively being imposed on mostly rural communities without consultation or localised benefit (Cowell et al., 2011).

Emerging visions: flexibility

The main problem to which visions of electrification were responding was systemic dependence on fossil fuels in the face of climate change. They did not take into account other problems, however, especially the unsuitability of the existing power grid for a system based on distributed RE. Visions of 'flexible' energy systems also emerged during the same period (CCC 2019) in the UK, USA, EU and Korea in particular. Representing an alternative pathway to that promised by electrification, flexibility promised a decentralised ('many-to-many') energy system, based on distributed, intermittent forms of renewable energy integrating a range of energy vectors as well as electricity (Ofgem, 2017), featuring in the UK Government's Clean Growth Strategy (BEIS, 2019).

Traditional 'one-to-many' centralised energy systems exhibit flexibility. Producers are able to bring assets online or take them offline to meet shifting demand. Many-to-many, intermittent production, requires, however, new distributed forms of energy storage (such as power-to-gas) and demand-side management to ensure intermittent generation is backed up and also able to cope with variations in day-to-day and interseasonal demand (Ofgem, 2017, p. 4). Flexibility represents, at one level, a critical response to how electrification was implemented, as it explicitly calls for grid remodelling and reinforcement, as well as integrating within the system a variety of energy vectors, including e.g. hydrogen and biogas as well as electricity, to build storage into the system while avoiding the high expected costs of relying on batteries. Nonetheless, while flexibility represents a more disruptive transformation of the current energy system, it retains some elements of business-as-usual: 'discussions of flexibility are generally about finding ways of making greater use of renewable sources of supply whilst continuing to meet current patterns of demand and maintain contemporary societal rhythms' (Forman & Shove, 2019).

While visions of flexibility are still emerging, they are arguably already creating performative effects, particularly in the UK context. These effects are being felt in reframings of governance in terms of a 'regulatory framework for a smart and flexible system' (Ofgem 2017, p. 6) designed to preserve the existing market logic of the energy system. A central aim set out for governance is the preservation of competitive markets in flexible energy provision, reflecting dominant economic models of innovation that see market price signals as the main driver behind transitions (Scrase & Smith 2009):

> *Our approach is not to favour one type of flexibility over another, but to allow different forms of flexibility, including forms which will be developed in future, to compete against each other, and against more traditional solutions [e.g. nuclear, offshore wind, and large scale hydro], within a market framework (Ofgem, 2017, p. 10).*

In addition, where visions of electrification tended to represent systemic changes in technology and infrastructure as largely homogeneous, flexibility implies more uneven patterns of development. For example, in urban contexts district heating systems are envisaged as important for providing low-carbon heating while in rural ones heat pumps might be more efficient (DECC, 2013). A range of ideas about what kinds of demonstrators are required to test the credibility of visions of flexible energy generation as responses to the problems within the dominant regime are thus beginning to circulate and to influence policy decisions about strategic directions (DECC, 2013).

Having surveyed the scholarly literature to explore the role that visions play in socio-technical change, and how relationships between visions and demonstrators can play out in different ways, we turn now to empirical data on how ideas about flexible energy system demonstrators are being developed as part of a project based in South Wales, UK, which addresses flexibility at regional (i.e south and north Wales) as well as city, town and village scales. Interviews with project experts and partners lay out how there is interplay between national-scale ideas about flexibility (including technological but also regulatory and other elements) and the development of visions for individual demonstrators. The unevenness and localised heterogeneity that is expected to characterise flexible energy systems is a major theme of the interviews. This unevenness, however, is expected to be a product of a combination of geographical and social circumstances. Among these social circumstances are expected to be values and concerns that will affect the acceptability of demonstrator projects to host communities. Consequently, visions for demonstrator projects that begin to emerge within interviews do not simply translate national-scale visions into local contexts. Rather, interviewees draw on localised circumstances in describing a range of possibilities for how forms of flexibility might be realised, depicting them also as primarily dependent for their final form on political choices in which a range of actors will necessarily be involved.

These expert visions or imaginaries should not therefore be taken to represent a collective ‘normal’ from which the perspectives of publics should then be seen as divergent and potentially as deviant (cf. Tidwell & Tidwell, 2018). Instead, our findings stress that expert imaginaries are themselves not so homogeneous (Irwin et al 1999, p. 1312), and that they incorporate a significant degree of reflexivity towards dominant visions (although this operates, as we shall also see, within limits).

Methodology

FLEXIS is a collaborative project involving the universities of Cardiff, Swansea and South Wales in Wales, UK. The project has built links with businesses and the local council in the industrial town of Port Talbot to connect together demonstrator projects with local industry (including Tata Steel). Alongside multiple engineering work packages, FLEXIS incorporates a social science component, which involves three workstreams (WS). This paper uses data from WS1 expert interviews. WS 2 and 3 are exploring energy use and everyday life in various locations, and WS3 uses place-based deliberative methods within Port Talbot to reflect on the diversity of local energy system imaginaries among community members in south Wales.

Twenty semi-structured WS1 interviews, each of approximately 90 minutes in length, were undertaken with individuals occupying different roles in the project, including principal investigators and senior researchers from across all FLEXIS engineering work packages, together with key project partners (representatives of private industry or local government involved with specific demonstrator projects), between October 2016 and April 2017. The analysis utilised a thematic approach based on grounded theory (Henwood & Pidgeon, 2003). This began with central issues raised by the literature review, including visions of system flexibility, how demonstrator visions are articulated (and linked – or not – to system visions) and questions about how credibility for both system and demonstrator visions can be established. Using examples of visions of electrification from the literature as background, we read the data for experts' assessments of tensions within the existing regime, looking for evidence of how they articulated visions as responses to such tensions. We were also interested in other ways in which experts sought to rhetorically establish credibility for visions, and finally in tracing potential performative effects of ideas about sources of credibility in the present. In this way, we treated expert interview data not as a way of accessing specialist knowledge but instead as 'a theoretically rich conceptualization of (implicit) stores of knowledge, conceptions of the world and routines' (Bogner & Menz, 2009, p. 48), particularly relating to how experts exercise reflexivity by self-consciously reflecting on where credibility for visions may come from and how it relates to solving problems in the current energy system. In this way, our intention in analysing data was to map diversity and heterogeneity among expert visions where it existed, rather than only to draw out what they share. Pseudonyms, along with role identifiers are used alongside quotations from data throughout the presentation and discussion of data. Roles are given in the text alongside pseudonyms.

FLEXIS and flexibility: system-level visions

FLEXIS aligns itself with aspects of system-level visions of flexibility, as documented in Ofgem reports (2017), e.g. in the project's business plan (FLEXIS, 2016), as well as on the project website (http://flexis.wales), launched in 2017. The website states that 'developing flexible energy systems' is the project's aim and is societally a 'major priority', which will require 'increased use of renewables as well as other forms of low carbon electricity.' (FLEXIS, 2016, p. 18), mirroring Ofgem's mention of allowing competitive 'traditional solutions' to energy supply.

This prioritisation of flexibility has performative effects on how research strategy in the project is described, setting out intentions to develop as the basis of the whole project new methods of modelling multi-vector energy flows (electricity including electricity and gas) across networks.

> *Interactions and dependencies between different energy systems are complicated and poorly understood, which significantly increases the difficulties of optimal planning and design of the integrated energy system*[1]

Addressing this issue is a response to one of the blindspots in visions of electrification mentioned previously, i.e. the neglect of interactions between energy vectors, specifically between electricity networks and gas networks (Qadrdan et al., 2015). The main route to addressing it will be to facilitate development of networked place-based demonstrator projects (including district heating and hydrogen power to gas storage), as in the village of Caerau in the Welsh Valleys (FLEXIS, 2016, p. 81) and also within the industrial town of Port Talbot.[2] Developing networked demonstrator projects is expected to contribute to improving socio-economic conditions in Wales, encouraging business growth and training opportunities, implying that a decarbonised future is also one of increased energy demand, reflecting tropes of

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[1] http://www.flexis.wales/research-item/wp1-integrated-energy-supply-systems-3/
[2] http://flexis.wales/demonstration-area/

ecological modernisation (Lorek & Spangenberg, 2014), particular in mentions of the Welsh Government's 'green growth agenda' (FLEXIS 2016, p. 18).

Networked, place-based demonstrators thus form the basis for aligning the energy values (Levenda, et al., 2019) of sustainability, security and affordability embedded in the trilemma with broader socio-economic values and priorities. Delivery of these demonstrators is expected to build a 'critical mass'[3] of research capacity as the 'foundation for the envisaged long term sustainability of the FLEXIS project' (FLEXIS 2016, pp. 99-100).

Unpacking flexibility

The FLEXIS project thus sets out a system-level vision of flexibility that prioritises both the need to explore the potential roles of different energy vectors within the system, but also echoes Ofgem's expectation that competition between different kinds of flexibility will drive decarbonisation in the UK energy system. A central theme that emerges from our interviews, however, is that individual FLEXIS experts see political choices as an essential 'control' on how competitive markets in energy provision operate. An example experts cite of why such interventions in energy markets is necessary is the performative effects of visions of electrification. Such visions are seen by several interviewees as having been politically attractive because they promoted an incremental narrative of homogeneous change across the energy system: 'part of the argument in those earlier days of the establishment of the wind electricity industry was we're not going to cause problems with the system' (Edward, principal investigator). However, the unintended consequences of rapid development of wind projects highlighted the need to move towards new forms of dynamic flexibility within the system via strategic decision-making: '[with electrification] you've got real fundamental problems that need to be solved, partly on the intermittency issues, massively on the seasonal storage and grid reinforcement' (Christopher, researcher). But political choices needed to be taken by UK government, the devolved governments (given FLEXIS's focus, the Welsh Government in particular) and local councils to shape the forms flexibility would take.

Interviewees therefore tended to expect that a flexible national energy system will most likely be developed unevenly. They anticipated that it would be built out of subsystems constructed at various scales ranging from neighbourhood to settlement to local authority boundaries, with these subsystems being seeded by the development of demonstrators networked in various ways. Two key themes in our interview data elucidate how these uneven patterns of development may play out. First, heat and power services are expected to be provided through a range of technologies, vectors and grid structures shaped by considerations that are both social and geographical. Second, experts also acknowledge that another source of unevenness will be how political decisions prioritise different values in service infrastructure design, some directly related to energy services and others not. For example, design choices may prioritise aspects of end-user interactions with devices and infrastructure, such as comfort, convenience and controllability (Shove 2003). They may, alternatively, prioritise values such as socio-economic development or community well-being and resilience. We now discuss in more detail these themes in relation to a variety of early-stage visions articulated by experts for socio-technical demonstrators, before focusing in more detail on one concrete example, a geo-thermal district heating network in the south Wales Valleys.

Transforming grids: islanding versus interconnection

Geographical and social conditions vary widely between rural mid- and north Wales, southern urban centres, and the post-industrial, materially deprived peri-urban settlements of the Valleys (Statistics for Wales, 2008). Experts envision FLEXIS demonstrators as needing to be responsive to these distinct contexts. Where visions of electrification focused on how energy was produced, interviewees often foreground distribution infrastructure instead as central to

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[3] http://flexis.wales

flexibility, with new forms of storage in particular needed 'to make the flexibility of the system, the energy system grid, real' (Alistair, researcher). Imagery of nodes and grids is typically used to imagine how socially and geographically-heterogeneous locations might be networked together.

> *Each individual entity has to control its own destiny but on the other hand it's also there to interact with the next one along so there is a relationship and how big that node is could be ten houses, could be a hundred houses or a thousand. (Jason, principal investigator)*

Decentralisation of energy production and distribution networks is often seen as the best response to this heterogeneity, building from the bottom up a regional reorganisation of the energy system.

Grid reinforcement is also a necessity alongside any trajectory of decentralisation to resolve key issues of energy security.

> *A lot of the areas in Wales [...] are at capacity so if you want to connect to the Grid you have to reinforce the Grid and that takes… it's very difficult to get industry into parts of Wales because they can't get the power supply (Aled, principal investigator)*

Decentralisation and reinforcement are thus also seen as a way of serving other perceived needs, by extending grid connections into rural areas to foster economic development there. Decentralisation is therefore seen as a strategy which might fulfil a range of needs, including system-level ones, but also ones that reflect uneven historical patterns of socio-economic development within Wales. Within this general strategy, interviewees identify two distinct directions in which it may be pursued. Some view a tendency toward self-sufficiency for certain nodes in the network as worth promoting. Others stress the necessity of interconnecting and nesting (mainly power) grids at different scales. A picture emerges of diverse and co-existing visions of decentralisation, shaped by social and geographical factors and anchored around particular proposed demonstrators. A prospective socio-technical transition is therefore seen as shaped by interactions between niche-level demonstrators and a national-scale socio-technical regime, but in ways that will be shaped by geography and place (Späth & Rohracher, 2010).

For example, some experts envision 'islanding' of power or heating grids as a key tendency within decentralisation. At the extreme, this may imply that some communities move entirely off-grid. For example, power-to-gas energy storage demonstrators using ammonia as a vector are envisaged for rural Wales: 'Those small communities are going to be on their own again because of economics' (Noel, researcher). Other similar demonstrators may enable increased self-sufficiency while also allowing wider grid connection as back-up in rural contexts.

> *when the grid goes out they've got enough to run all essential services, it keeps everyone's refrigerator going you know it keeps you know air conditioning when it's in the middle of summer going, it keeps the hospital going. (Jason, principal investigator)*

For other contexts, and at a different scale, islanding based around networked hydrogen power-to-gas demonstrators is also seen as an option for cities, given adequate political support: 'given the right funding it's not unreasonable to have the whole of Swansea effectively off Grid in ten years' (Christopher, researcher). Here, flexibility is imagined in terms of being able to substitute alternative vectors ('flexible fuels', Anthony, principal investigator) for natural gas and/or electricity delivered through the national grid: 'being independent as well from the grid is I think more flexible than actually being completely fed by an entire system' (Noel, researcher).

Alternatively, other experts imagine maximally decentralised, flexible energy infrastructure as a system of subsystems, incorporating nested levels of dense interconnectivity to create a new ‘topology of the network’ (William, researcher). Where such systems are developed, it may be because of the costs of pursuing islanded systems in some localised contexts: ‘It has not been demonstrated that [islanded systems] are always cost-effective’ (Clive, principal investigator). Denser, multi-level interconnection is imagined as developing through disruptive growth in numbers of prosumers deciding to ‘group together and trade energy amongst themselves’ on a peer-to-peer basis, making possible neighbourhood and town/city level grids, as a ‘utility company needs to be there to make sure we’ve got a buyer of last resort’ (Clive, principal investigator). By providing data that enhances network stability and energy security, such networks will increase grid flexibility by making patterns of demand more predictable: ‘the generators will know my pattern together with you know a hundred thousand others.’ (Clive, principal investigator). Developing local demonstrator projects in larger towns like Port Talbot is envisioned as seeding larger networks (Naber et al., 2017) by helping provide ‘clarity for people who want to invest or innovate on network storage’, helping to determine where batteries or other forms of storage need to be sited (Kevin, researcher).

Some experts suggest that a significant benefit of rebuilding grids by creating nested, interconnected structures from the bottom up will be that the need for significant grid reinforcement may be reduced in places:

> *So if we can achieve this peer-to-peer network and then make energy balance in the local area we use the less of the transmission line using less of the assets will mitigate some issues like with elimination in the network. […] We need to get the network stronger and bigger but we don’t need that if we are using different methods, like using the flexibility in the demand side. (Kevin, researcher)*

In the Welsh context within which interviewees are located, bottom-up decentralisation is thus imagined either through increased self-sufficiency for more isolated areas or in terms of nested levels of interconnection in areas of denser habitation, Rather than such trajectories being seen as reflecting a market logic, they are seen as resulting from values-driven interference with such a logic, reflecting political analyses of the needs of specific localities.

Prioritising values: households and communities

The role of demonstrators in establishing credibility for visions of a flexible energy system is not just seen by experts in terms of technical viability. They are also hoped to increase credibility by proving the benefits of energy system change to potential end-users, including domestic and business users, and policy stakeholders:

> *[…] we’re using the project as a platform to test new technologies, to test new business models, new finance structures, looking at opportunities for the supply chain, for job creation, training, addressing fuel poverty as well as obviously lowering our carbon emissions. (Ffion, local authority)*

Questions about what benefits might follow from energy system change ‘ideals of what energy systems should be, should do, and how they should help deliver socially desirable outcomes’ (Levenda et al 2019, 183). Examples of such ideals are reflected in experts’ discussions of the distinct ways in which different demonstrator projects might help shift relationships between users and the energy system itself, and that these values provide examples of how the transformation of the energy system from the bottom up is being ‘pursued for all sorts of other reasons’ (Clive, principal investigator) other than cost-effectiveness.

Controllability is one value some experts see as central to a more flexible energy system. Demonstrators that are expected to make energy infrastructure more present to end-users are seen as promoting controllability. At one level, interviewees view some demonstrators as experiments with controllability in ways that have become familiar from the development of ‘smart homes’, enabling end-users to take up a more actively managerial relationship with their household energy use (Strengers, 2013). Neighbourhood experiments with peer-to-peer energy trading in Port Talbot based on PV for households and individual businesses, for example, are envisaged as enabling end users to periodically 'feedback their preferences' (William, researcher) through home energy management systems to enable flexible systems to predict their needs more accurately and thus dynamically balance production and demand. Greater controllability may mean electricity can be purchased more cheaply, but also promote an increased sense of autonomy for households that comes with direct active participation in the energy system, making and 'storing energy locally' (Aled, principal investigator). More control will come with an 'element of reward' for managing one's energy use predictably, thus enabling system actors to 'plan and manage the whole infrastructure' (Kevin, researcher). Tangible benefits to households are expected to go hand-in-hand with increasing flexibility within the system, which will in turn promote energy security more generally.

Peer-to-peer trading networks could also be realised along alternative lines, prioritising other values – such as convenience. Using blockchain technologies to potentially automate energy trading via 'smart contracts' (Merz, 2016) might enable home energy management systems to switch customers to the most advantageous tariffs when needed without their direct involvement, based on fluctuations in predicted demand. Predictable demand across regions of the network would automatically accumulate financial benefits for users, with network costs being paid for by increased tariffs for customers whose actual demand often failed to 'match predicted demand' (Kevin, researcher).

Values that represent benefits which are more collective in scope are also associated with specific projects. For example, in setting out expectations for urban power-to-gas projects based on electrolysis of hydrogen, an expert describes a demonstrator initially in pedagogical terms, emphasising its value as a means of 'correcting' perceptions regarding the risks of hydrogen. But this idea of education is then immediately expanded to describe how demonstrators could enable communities to re-imagine what kinds of assets (often materially-deprived) communities could have control over. By embodying self-sufficiency, a more islanded system is envisioned as producing a sense of 'ownership' (Christopher, researcher) of technology among publics, very different from a regime in the present where 'there's no relationship between [the end-user] and the light switch'. More self-sufficient, islanded systems are thus associated with a shift in the meaning of energy as a collective resource.

Other interviewees make links between demonstrators and collective values in exploring how islanding or interconnection might connect to the history of the places in which demonstrators might be developed, echoing the points made by Levenda et al (2019) regarding perceived connections between energy systems and values of democracy and independence.

> *[…], so the question is in a neighbourhood, do you all produce the power and yes you store it within the house but how do you interact within the neighbourhood? […] Well now you're going back definitely pre-Industrial Revolution to you know little communities who shared the cow or whatever right? The resource. (Jason, principal investigator)*

Here, direction of travel of changes in grid connectivity is seen as potentially in harmony with particular non-neoliberal traditions of politics, and ones in particular which other experts (Lowri, LA; Rhys, small/medium enterprise) point out are reflective of the political history of Welsh Valleys communities . As we saw, islanding and interconnection were seen as different trajectories in which network transformation might move, driven by political choices sensitive to community characteristics and needs, rather than market logics. When it comes to considering what values demonstrator design should prioritise, community characteristics are once again thought to be important.

Envisioning projects in place: mine water-based district heating

Many of the FLEXIS demonstrators around which interviewees construct outline visions (such as power to gas or peer-to-peer energy trading) are seen as only possible in 5-10 (or more) years. However, a specific example of a near-term project currently in development was also discussed by several interviewees. We now examine this case site in more detail to explore how the themes already identified are present in the visions interviewees articulate for this project. Experts' knowledge of local conditions and community perspectives is reflected in their sense of how political decisions will need to be made in transforming the local network and in prioritising particular values relevant to the needs of the host community.

The project in question is one that will use water from flooded mine workings beneath the village of Caerau near Bridgend in south Wales as a low temperature geothermal heat source for a district heating network. The aim is to serve the heating needs for a mixture of owner-occupied, privately-rented and socially-rented homes in a materially-deprived setting. Project officers have used the Energy Path Networks modelling tool developed by the Energy Technologies Institute as a way of building potential pathways for energy transition in response to local circumstances (Calderón et al., 2019) to explore three potential visions for the project:

1) a centralised system with a single 'energy centre', where a heat pump will heat water pumped out of the mines and then distribute it to end-users.
2) a decentralised system, in which mine water will be distributed to end-users before being heated by individual heat pumps.
3) a hybrid, with several energy centres around the village to heat and distribute water to end- users.

This project therefore represents a potentially islanded heat network that could perhaps be entirely off the gas grid, based on a local heat source that provides 'fuel flexibility' (Anthony). The project could also potentially be islanded in relation to the electricity grid too by 'connecting it to a local windfarm' (Lowri, local authority).

Determining which of these three disruptive paths a vision for the project should take requires project actors (local government, industrial partners, Welsh government, UK government agencies) to take decisions about which energy values to prioritise. Understanding the social priorities relevant to less 'robust' or 'resilient' communities like Caerau in which fuel poverty, and poverty more generally, are 'concentrated' (Lowri, local authority) is seen as crucial for such decisions and for building credibility for whichever vision is chosen. Significant financial benefits have been associated with other similar geothermal projects (e.g. Sust, 2013). But how extensive these might be in Caerau remains uncertain ('What's the benefit? You might save a little bit of money,' Huw, researcher).

The extent of such benefits is expected to be dependent on which of the three distinct visions are chosen, but will also be influenced by existing inequalities in housing quality and health within the village. Ultimately, the 'two main drivers' that will shape which model is chosen for the project are seen as fuel poverty and developing a scheme 'that generates jobs in the area', with whether it has a 'big effect on health' also being a factor, with such effects being seen as likely significant but hard to measure (Stephen, local authority). The provision of new employment or training is seen as likely to be easier to measure but relatively small (Huw, researcher), by contrast. High unemployment in Caerau is seen as deriving from intractable 'intergenerational' socio-economic conditions (Lowri, local authority) which a project of this nature cannot by itself address. Financial savings for participating end-users are expected to be relatively marginal. Indeed, under option 2, the more decentralised vision with increased use of heat pumps, it was thought that household heating costs could well increase, especially if the project were to be powered by the local wind-farm (Ffion, local authority).[4]

[4] More recently, these estimates have been revised, with connection to the local windfarm now being seen as economically viable and even as possibly reducing cost [Author, under review]

Interviewees also see less tangible collective benefits as potentially being important, which may derive from the relationship between the project and the community's history. There still remain, for example, positive emotional attachments in the village to industrial heritage such as coal mining, shaped by local perceptions of its contributions to economic prosperity and community identity – despite there also being keen local awareness of its lingering health and environmental impacts. Indeed, the mines are seen as representing for local people a past of relative abundance, both economic and in terms of energy, through the free coal allowances made available to colliers' families. Using the flooded mines for localised energy is expected to be seen by many local residents as 'bringing the mines back to life' (Rhys, small/medium enterprise). A future associated with the mine water project might not be directly comparable with the economic and energy abundance of the fossil-fuelled past. At the same time, there are expectations that a more tangibly present local heating system might represent for locals self-sufficiency, and with it, a degree of resilience in energy terms for a deprived community vulnerable to fuel poverty (particularly if the project becomes islanded by linking it to the nearby wind farm). Further, this association with self-sufficiency may, through the project's connection to broader visions of decarbonisation, be linked to expectations about continuing environmental improvement in the area following the end of coal-mining. This new pairing of values has to be included in 'teasing out social gains from doing [the project]' and giving these 'appropriate weighting' against possibly marginal financial gains (Stephen, local authority).

At the time of interviews, the final decision between options was some years away. However, discussions about the non-financial benefits the project might bring had already begun to exert specific performative effects on project governance. First, a 'community champions panel' (Huw, researcher) was seen as necessary in order to broaden engagement with the project community 'to talk to people and understand what they value' (Stephen, local authority) early on, to help understand better how to realise a wider range of potential community benefits and also to understand possible disbenefits of the three different visions. Second, the need to choose one of three visions had led to a broader discussion among project experts and stakeholders about how to construct a business model appropriate for Caerau. The question of whether to subsidize poorer households' participation in the scheme, given potential health and other benefits and the higher energy costs experienced by such households, was seen as particularly important.

> *In other words the business model will show they're paying let's say £400 or a £1000 a year at the moment for the heating they're getting, they're going to pay £1500 a year from now on but it's constant and when they want it and it's whatever, they can't afford that £500 someone else will have to pick it up basically for now. (Rhys, researcher)*

At the same time, the potential of community ownership for a more islanded energy system was also seen as raising ethical questions. Such models might promote a variety of social benefits, but also raise questions about community capability and future-oriented responsibility:

> *If in five or six years' time the [mine]water has just dropped in temperature you know where do they go from there really? Are [the community] responsible for putting a whole new system in for themselves or what do they do?' (Rhys, researcher)*

The work of visioning brings into the present two key issues, regarding what is valued within the community, but also the best ways to support a community that is moving towards a model of heating that may be increasingly islanded and might also realise more intimate, tangible relationships between users and infrastructure.

Discussion

Problems may be created where dominant socio-technical visions are translated into a variety of different local contexts via demonstrator projects in ways that are unresponsive to local conditions. Such visions are inherently political, insofar as they promote specific futures from which particular values and concerns (especially those of the communities where demonstrators are located) may be excluded. Research on conflicts surrounding demonstrator projects shows that the involvement of publics can produce 'informal' varieties of technology assessment that question the inclusiveness and credibility of visions (Cloke et al., 2017; Pesch et al., 2017). However, the 'possibility of disagreement and contradiction' within expert perspectives (Irwin et al., 1999, p. 1312) – even outside formal 'arenas of expectations' – may also lead to critical reflection on the credibility of visions, as our data from South Wales underlines. Demonstrator projects are understood as experiments that test the credibility of visions in conditions that include public responses, regulatory regimes, business models and other considerations beyond the purely 'technical'. We have shown how experts working on and with the FLEXIS project are engaged in constructing visions for demonstrators in ways that open up reflexive distance between these visions and some of the key elements of dominant, system-level visions of flexibility, as well as towards aspects of previously-dominant visions of wholesale electrification. Some of these key elements are mirrored in the high-level whole-system vision set out in the FLEXIS project's own business plan, such as the idea that building flexibility into the energy system will be led by the economic competitiveness of different low-carbon solutions, including more traditional ones (such as nuclear power) and more emergent varieties (such as hydrogen power-to-gas).

Those aspects of this visioning work where such reflexive distance is most evident can be summarised as follows. Non-market forces, non-technological factors and values other than those represented by the energy trilemma are seen by experts as likely to exert significant influence on what forms flexible energy systems will take. The idea that preserving a competitive market in energy provision will be the main mechanism for driving a transition to a decarbonised energy system is thus challenged. As some STS scholars have argued, socio-technical transitions are actively *made* through the alignment of 'artefacts, actors and institutions' (and in the case of energy systems, we might add, places with histories) carried out through visioning, rather than simply being driven by price signals in innovation markets (Scrase and Smith 2009, p. 716). The diversity of social and place characteristics in Wales (e.g. urban neighbourhoods, peri-urban Valleys settlements, rural communities where services like gas and broadband internet can be difficult to install) is reflected in experts' views on the *unevenness* of how flexibility will be realised through decisions that are dependent on political decisions at local authority and Welsh Government level.

The FLEXIS business plan emphasises that visions of flexible energy systems need to focus on how energy distribution will work across energy systems, rather than following the main focus in visions of electrification on how energy is produced. Experts developing networked demonstrators follow this emphasis on distribution by constructing different visions of grid structures. They see choices as needing to be made between the development of more islanded grid structures or more densely interconnected, multi-level networks. Rural and peri-urban communities are seen as potentially better supported by more islanded (or even off-grid) systems that rely on fuel switching ('flexible fuels', Anthony, principal investigator) and alternative forms of storage like hydrogen and ammonia. Denser interconnection between highly-localised and wider grids, incorporating demand-side response systems (including peer-to-peer energy trading) is seen as more viable for neighbourhoods within larger towns and cities. Design choices also need, experts expect, to be more explicitly inclusive of a wider range of values, some of which are directly related to the ways in which energy services are provided (like controllability and convenience), and others not so (such as health and community resilience).

Credibility for demonstrator visions is not, therefore, seen solely as an effect of how far they reproduce key elements of a dominant whole-system vision, and not, in particular, how attractive they might be to investors within a competitive market. Instead, it is seen as being dependent on how a diverse set of actors (including academia, industry, local government, devolved governments, UK government) can collaborate in making decisions that are appropriately responsive to the circumstances of demonstrator host communities. While recognising the market-based regulatory environment in which the UK energy system is embedded, experts envision system change as requiring strategic interventions that are responsive to the local contexts of demonstrators, including a range of needs often overlooked within energy policy. The Caerau geothermal demonstrator exemplifies how FLEXIS experts see complex political choices about values and infrastructure configurations as shaping what flexible energy systems that integrate different energy vectors may look like. As a strategy for decarbonising the energy system, experts thus interpret concrete realisations of flexibility as resulting from a 'variety of actions and changes' 'some of which may originate from the non-energy sphere' (Torriti & Green, 2019, p. 67), rather than simply as being reflections of national-scale visions whose final form is shaped by market forces.

The reflexive distance created through the development of demonstrator visions in response to localised circumstances remains circumscribed, however. In particular, the development of flexible energy systems is expected to go along with inevitable increases in energy demand (Shove 2003), re-establishing a link between decarbonisation and a 'green growth agenda' (FLEXIS 2016, p. 18) in which maintaining or increasing current levels of energy demand will be necessary (Willis & Eyre, 2011). Interviewees tend to see the development of spatially differentiated and fuel-flexible systems in a Welsh context as promoting economic growth in materially-deprived rural and peri-urban areas (Aled, principal investigator). The assertion of a necessary link between decarbonisation and growth is not universal, however, as noted above in our discussion of the Caerau case. Here, scepticism about the link between localised energy systems and economic growth is accompanied by views that developing such systems would be justified, instead, by the socio-economic and place characteristics of particular communities.

Conclusion

What flexible energy systems will look like in practice remains highly uncertain. However, any increasingly decentralised, many-to-many system poses challenges for established ways of constructing visions of socio-technical change, which often position individual technologies as protagonists in narratives of change that play out across a largely homogenous system, driven by market forces. We have seen that the experts we interviewed envisage flexible, integrated energy systems as taking on highly spatially differentiated forms across an increasingly decentralised and uneven system, reflecting the importance of understanding large-scale socio-technical transitions through a geographical and spatial lens (Smith et al. 2010). While affordability of energy is seen as potentially important for end-users, demonstrator projects on the ground are expected by the experts in our study to be shaped by criteria that reflect broader needs and values, history and place. This may thus affect what criteria are used by energy system actors to establish whether local or system-level visions are credible or not.

The localised visions of flexible systems beginning to be articulated around FLEXIS demonstrators echo themes emerging elsewhere. For example, in the Green City Vision project report (Progressive Energy, 2019), a regionalising strategy is contrasted with the influential four national decarbonisation scenarios produced by National Grid (National Grid, 2018). The emerging visions in our study also add, however, reflections which echo the points made by Cloke et al (2017), among others, regarding the ways in which a lack of inclusiveness and responsiveness to societal values may promote public scepticism about motivations for change (cf. Ballo 2015, p. 10). Experts in our sample tended to view the potential effects of such a lack of inclusiveness on the credibility of demonstrators as negative.

Our data raise two important outstanding questions. The first of these concerns the extent to which reflexivity towards dominant visions is indeed promoted through expert engagement with localised demonstrator projects. The visions we have explored here respond critically to previous visions of electrification and also diverge from dominant visions of flexibility. At the same time they reproduce some assumptions that underlie dominant visions. For example, reduction of energy use is mentioned rarely, mainly considered last as a potential output of difficult, individual-level behavioural change It may be that the idea, as expressed by experts working in Caerau for example, that early engagement with communities is necessary to understand needs remains tied to fostering social acceptance by trying to find out what people need and then providing it, rather than creating opportunities to uncover and test perhaps more fundamental assumptions that may be reproduced within future visions.

The second question concerns how technological niches may relate to broader system change in any transition towards flexible integrated energy systems. The development of local systems around demonstrator projects may create divergence from national-scale visions and invite reflection on their credibility. However, it is unclear to what extent such projects can – given the expected uneven and heterogeneous trajectory a decarbonised energy system might take – scale up according to traditional models of the effects of niches on mainstream regimes (Naber et al., 2017): 'the biggest risk we expect to find developing projects like this [Caerau] is when you scale' (Tomos, small/medium enterprise). Whether the lessons learned can be effectively translated into other localised contexts, or how they can influence the further development of system-level visions remains an open question requiring further work.

These two questions open up additional avenues for research. In particular, they invite further work on how stakeholders, including publics, can effectively engage with complex system-level and localised visions in ways that facilitate reflection in the fullest sense on the performative, nurturing work that visions may be doing in the present. They also invite further work on how to articulate system level visions that fully acknowledge differentiation and complexity within the energy system.

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