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Original research article

Accelerating transitions? Planning for decarbonisation in local and regional energy systems

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ABSTRACT

Local and regional energy systems are recognised as an important area of the global transition to clean energy, but one which requires novel approaches to energy governance. In this paper, we frame local and regional energy systems as experimental spaces for the introduction of new technologies and processes. We reflect on certain acceleration conditions that are needed to move beyond this experimentation phase to meet transition goals, and in particular the role of user intermediaries to enable these systems. Focussing on this acceleration phase of transitions, we analyse three distinct aspects of planning in the local and regional energy system transition in Great Britain - local government-led energy planning, dispersed industrial site decarbonisation, and business planning for the electricity distribution networks We discuss how a 'governance gap' has developed, due to a patchwork approach to energy planning, with roles and responsibilities poorly defined and policy only targeting one user intermediary role. We suggest the lack of coherence across energy planning is limiting the ability of local and regional systems to accelerate to meet the UK's net zero target.

1. Introduction

Meeting the United Kingdom's (UK's) 2050 net zero commitment will require 'pace, not perfection' [1]. In pursuit of this aim, the new Labour government has committed 'to make Britain a clean energy superpower with zero carbon electricity by 2030, accelerating our journey to net zero' [2]. Pathways and scenarios suggest these targets can be met but will require a range of large- and small-scale resources and a variety of consumer and demand side interactions [3]. Yet, recent clean energy policy in Great Britain (GB)[1] has focussed more on accelerating large scale electricity generation and transmission, in line with the legacy of largely centralised oil and gas infrastructures, markets and regulation, with comparatively less policy attention on decentralised and distributed resources. Despite this, distributed generation now accounts for circa 29 % (30 GW) of electricity capacity in GB [3] and there is increasing cross-sector recognition that making best use of such distributed resources, alongside the integration of heat, power and storage, should provide significant whole system benefits [4].

However, the use and uptake of distributed resources is uncertain and requires a system that can respond to rapid change wherever and whenever it occurs, therefore requiring adaptive planning [1]. In recent years, strategic planning has increasingly focused on using system-based modelling, along with customer and stakeholder engagement, to explore potential transition pathways. This approach aims to unlock the benefits that local and regional systems could bring to a decarbonised energy system while identifying possible system challenges (e.g. [3,5]).

By focussing on energy system planning in three sectors: local government, dispersed industrial sites, and electricity distribution networks, this research provides an empirical review of evolving local and regional energy governance practices in GB. We identify emerging planning processes at a local and regional level, consider whether these processes are consistent across sectors, and evaluate early impacts and

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[1] This paper refers to the United Kingdom and the United Kingdom Government when referring to energy policy. However, the single energy market and the economic regulation of the energy networks does not include Northern Ireland, and so our analysis relates to Great Britain, comprising England, Scotland and Wales.

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future implications of energy planning practices. Energy system planning is particularly important given the increasing debate around the role of distributed energy within local and regional energy systems, and how the integration of heat, power, and storage can contribute to net-zero GHG emissions and meeting the 2030 target for a clean power system [1,2,6].

This paper synthesises three interlinked research projects on local and regional energy systems conducted within the UK Energy Research Centre, each of which identified governance gaps in developing more locally and regionally integrated energy systems in Great Britain (GB). Although multiple efforts to 'transform urban governance and planning regimes' towards sustainability are taking place globally, there is a lack of evidence on how such efforts are succeeding or failing to mobilise action [7]. This question is at the heart of our enquiry; multiple forms of local energy planning are currently developing in GB, and we suggest that there is a need to reflect on the evolution, outcomes, alignment and tensions between approaches and their implications for the governance of energy system transformation.

We situate this research in the context of accelerating transitions, as it is imperative that governance allows local and regional energy systems to move beyond experimental niches if decarbonisation targets are to be achieved. We suggest that planning in local government, for dispersed industrial sites and the electricity distribution networks can be understood as experimental processes that have introduced new practices, rules, and norms and are in various stages of acceleration and integration with each other (e.g. [8]). We provide examples of local and regional level policy and practice within each of these approaches, highlighting interlinkages, and possible challenges to the acceleration processes required to meet decarbonisation targets.

We then present new processes being introduced by the energy regulator, Ofgem, to enable strategic planning of the energy networks, including the introduction of a regional governance role – the Regional Energy Strategic Planner (RESP). We comment on these new processes as an initial attempt to enable an acceleration phase through a planned approach to net zero and outline further challenges to be addressed.

Our contribution is two-fold. First, we add to the empirical knowledge on governance for decentralised energy system innovation in GB by completing a cross-sector analysis to highlight any gaps and inconsistencies to be addressed. Second, we link evidence from our analysis of local and regional energy systems governance to the conceptual framework on accelerating transitions to highlight the governance challenges of delivering 'pace, not perfection' [1]. The remainder of the paper is structured as follows.

In Section 2, we discuss local and regional energy systems in the context of experimentation and acceleration of energy transition and present our research questions. In Section 3, we provide the methods used for the research. Section 4 presents our case studies of planning in local government, dispersed industrial sites and the electricity distribution networks. Section 5 discusses the challenges of accelerating transitions in local and regional energy systems while Section 6 considers the UK government response. Section 7 concludes.

2. Accelerating transitions for local and regional energy systems

The transition studies literature argues that successful socio-technical transitions will go through, broadly, three phases – from initial niche experimentation, to an acceleration phase, until an equilibrium stage is reached where the initial niche innovation enters, or becomes, the mainstream (e.g. [9,10]). The emphasis of much energy transition literature has been on experimentation and learning around novel technologies and practices within protected spaces [9,11], with a significant strand of research developed on the role of experimentation in urban and regional climate governance (e.g. [12–14]). A further noteworthy, but less researched strand, has investigated the 'acceleration phase' of transitions, where the focus is on deliberate and policy-mediated acceleration of niche experiments and innovations, leading to the establishment of new dominant designs and reconfigured systems (e.g. [9,15,16]).

2.1. Niche experimentation

A particular focus of research on local and regional experimentation has been the role of cities and urban areas in processes of sustainability transitions [17]. Literature highlights two roles of urban climate and energy experiments; i) as stepping stones to system change where learning through bounded 'test-beds' can ultimately lead to disruption of existing regimes [18], and ii) as a mode of governing whereby processes of experimentation act to shape discourses on problems, solutions, roles and relationships, creating scope for new urban politics [19]. Scholarship in urban studies and transition studies has started to explore these processes and the ways in which urban experimentation may shape wider processes of transformation [19,20].

In line with this second conception of experiments as a form of urban governance, we position experimentation in local energy planning as a route through which the politics of local energy system change are being negotiated. As Bridge and Gailing [21] emphasise, 'the sites, scales and spatialities of energy systems are key contemporary sites of struggle' (p.1042) through which broader questions of governance are navigated, challenged and/or reproduced. Simultaneously, the extent to which market and regulatory structures for local energy systems require reformulating is the topic of considerable debate [22]. There is increasing attention on *how* energy system decarbonisation might require more local- and regionally-based approaches to planning, integration and delivery as many local governance structures lack the necessary processes to coordinate and integrate innovations into common practice (e.g. [7,23,24,25]) and so the scope for these initial niche processes to enter an acceleration phase is limited.

2.2. Tipping towards acceleration

While the initial experimental phase tends to affect only those actors concerned by the niche technologies themselves, moving towards an acceleration phase has a broader reach as new technologies begin to compete with incumbent technologies and other complementary technologies and practices are introduced, affecting incumbent business models and governance processes [15]. In addition, governance dynamics for decentralised energy are not just local but shaped by vertical and horizontal influences, suggesting that the role, potential and challenges of local energy planning will also be embedded in broader multi-level governance relationships [26]. For example, while local energy governance experiments may seek to develop and test new configurations of actors, technologies, policies and practices, they often build on existing policies [25] which tend to be rooted in the path dependencies of historic centralised, fossil-based systems [26]. This raises questions about the transformative nature of local energy governance experiments and how they might contribute to processes of acceleration.

Roberts and Geels [16] recognise that prior to policymakers being able to accelerate transitions, various conditions need to be met to enable incumbent policy regimes to be altered. The authors describe *acceleration conditions* for innovation at the meso-level that include – (business) mobilisation of actors and networks around new technologies to lobby for policy change; (mass publics) shifting public opinion influencing policymakers; (technology) technological change creating the need for policy change due to changing system dynamics. The authors suggest that all three acceleration conditions should be in place, which may allow for political acceleration to speed up a transition. Policymakers do not have to wait for these conditions but can support their development through the use of policy instruments. They may, however, be unwilling to do so without voter or industry support for the change [26].

Through an alternative lens on users rather than conditions for accelerating change, Schott et al. [8] suggest that effective policy should

identify the *types* of users and understand how their collective routines are created, shared and reproduced; new polices could then be '*aimed at mobilizing the potential of users for challenging, changing and stabilizing shared and collective routine*' (ibid, p.1). They posit that it is the combined action of various user groups that accelerate a transition, broadly defined here as i) user-citizens, that initially lobby for reform to enable particular niches; ii) user- consumers who buy and embed products and new practices in their lifestyles; and iii) user-intermediaries who create spaces and configure the system through the introduction of new rules, regulations, processes and structures. The authors suggest that user-intermediaries are crucial to the acceleration phase, but often not targeted in the policy process. Therefore, we suggest that local and regional energy system planning, through the introduction of new rules and regulations via targeted local policy may create the processes and structures required to move into an acceleration phase.

Accelerating transitions necessitates a multifaceted approach that integrates socio-cultural, economic, political, and technological dimensions. Acceleration conditions are necessary to move beyond niche innovation, with acceleration being achieved through policy interventions aimed at user-intermediaries playing a pivotal role in mobilising stakeholders, fostering innovation, and managing the phase-out of incumbent systems. For local and regional energy systems the introduction of new technologies and processes requires planning and coordination to ensure a reliable, secure and affordable decarbonised system [1]. Therefore, the user-intermediaries influencing these processes include local government, industrial energy users and the energy networks. Through providing practical examples of local and regional level policy within each of these areas, we highlight possible challenges to the acceleration processes required to meet decarbonisation targets.

2.3. Acceleration for decentralised energy governance

It may be argued that acceleration conditions in GB have been met as the growth of new technologies and practices has created a need for policy change for both the physical system and its governance (e.g. [27,28]) with shifting public opinion causing many local authorities to declare a climate emergency [29]. Consequently, it may be necessary to target the user-intermediaries in the system to allow for acceleration of the new technologies and demand side processes. However, in the British historical context local and regional energy governance has been progressively hollowed out [30]. In contrast with many Northern European countries, local governments in GB have no formal powers over energy and very limited capacity or resources for engagement in clean energy planning and development [31,32]. Privatisation of the energy supply industries and network infrastructures in the 1980s and early 1990s was accompanied by increasing centralisation of control and the disappearance of a regional tier of energy businesses and governance [30]. The key actors at regional level are currently gas and electricity distribution network companies who have, historically, focused on network planning and investment in line with regulated economic incentives. Direct engagement between distribution network businesses and local government and other stakeholders, such as local industry, has been uneven, and formal requirements for such cross-sector and cross-network planning have been marginal [32]. Therefore, challenges may occur due to the lack of formalised user-intermediary roles. To further understand the challenges within local and regional governance when entering an acceleration phase we ask:

1. How is local and regional energy planning incorporated into accelerated transitions for net zero in the GB context?
2. In the context of a commitment to an accelerated net zero transition in GB, is there a coherent, integrated and cross-sector approach to energy planning at the local and regional levels?

A research methodology was designed to incorporate and analyse data gathered from the UK Energy Research Centre Local and Regional Energy Systems theme. The sub-themes of Devolution and Local Energy System Developments, Economic and Industrial Transitions and Regulatory Governance and Decentralisation took insights from previous and current research to create case studies that looked across planning in local government, local industrial decarbonisation and the electricity distribution networks. Using a cross-sector analysis, this research provides novel insights into the interlinkages between sectors at a local and regional level, and therefore the importance of user-intermediaries in accelerating transitions, thereby identifying governance challenges for GB's net zero goal.

3. Methodology

To answer the research questions, we provide practical examples to highlight the governance challenges of accelerating transitions. This paper synthesises data from three interlinked research projects conducted between 2021 and 2024 on local and regional energy systems in GB. These projects focussed on 1) devolution and local energy system development; 2) decarbonisation of dispersed industrial sites and 3) energy network regulation and governance. The data used in this research has been previously published in peer-reviewed documents, reports, conference proceedings and blogs [33–37].

All projects adopted a similar research approach, conducting detailed qualitative analysis of the processes by which policy and governance for more decentralised energy systems was developing in GB. Methods focussed on document analysis and expert interviews. The case studies presented in this paper draw on the range of interviews and documents analysed to present an overview of recent changes to GB governance and to highlight common challenges that may need to be addressed to fulfil the UK's net zero ambitions. Data sources are summarised in Table 1 and described below.

Interviews for case study A, local government-led energy planning, were carried out between February 2023 and April 2024. Interviewees were selected from desk-based research on key organisations involved in energy planning and delivery in the four locations of Fife (Scotland), Cardiff City Region (Wales), Greater Manchester (England) and the West Midlands (England). These locations were chosen to represent both geographical diversity and as areas with extensive contemporary experience of local energy planning. Interviews with locally based actors were supplemented by a range of interviews with national governments, Distribution Network Operators (DNOs), non-governmental organisations and consultants who were involved in local energy planning across GB. The aim was to explore how actors perceived the role of locally and regionally integrated energy systems, and the benefits and challenges of local energy planning. Interview questions focussed on understanding detailed approaches to local energy planning, challenges and benefits, roles and responsibilities, the role of pilots and demonstrators, as well as implications for national policy. Emerging findings were tested at a cross-sector stakeholder workshop on energy planning across scales in July 2023 (see [37] for a summary of the workshop and a list of attendees).

Interviews for case study B, the decarbonisation of dispersed industrial sites, were conducted with 30 expert respondents between July 2021 and November 2022. Participants were initially identified through their attendance at industrial decarbonisation webinars and workshops, with additional recruits obtained via snowball sampling. The selection aimed to provide a wide range of perspectives, including representatives from energy-intensive industries including cement, paper, ceramics, glass, chemicals, food, minerals, and metal processing, as well as trade unions, local authorities, decarbonisation projects, and research institutions working on industrial and place-based decarbonisation efforts, both in the UK and internationally. The primary aim of this original research was to establish what needed to be done at a local level to support the decarbonisation of dispersed industrial sites, explore the role that local strategies might have in this area, and identify policy implications. During the interviews, participants were asked about the status

Table 1
Data sources from the governance theme research used for the case studies presented. A list of interviewees is presented in Appendix II.

Case study	Interviews	Documents analysed
A. Local government-led energy planning	47 interviews with local and Combined government officers, Distribution Network Operators, energy consultants, industry representatives, NGOs and civil servants focussed on four locations of Fife (Scotland) Cardiff City Region (Wales), Greater Manchester (England) and the West Midlands (England). A local energy modelling workshop with 23 cross-sector attendees (excluding researcher attendees).	34 policy documents and consultations from UK, Scottish and Welsh Governments Plus multiple local government and consultant documents relevant to local energy planning in the four locations where interviews were conducted.
B. Decarbonisation of dispersed industrial sites	30 expert interviews with representatives from industry, local government, central government regional decarbonisation initiatives and think tanks.	18 Local Energy Partnership authored Local Industrial Strategies UK Government strategy documents on industrial decarbonisation authored by BEIS, DESNZ, the Prime Minister's office and HM Government
C. Introduction of strategic planning for the electricity distribution networks	14 expert interviews from electricity network regulation, the electricity distribution networks, trade body, consultancies and the energy system operator.	Electricity Distribution Network Business Plans Ofgem documentation on electricity distribution business plan methodologies and frameworks Ofgem working group slides and minutes Energy Networks Association - Open Networks reports and methodologies

of industrial decarbonisation in the interviewees' sectors, areas, or research fields; details of any decarbonisation initiatives they were involved in; their experiences with these initiatives; and their opinions on the effectiveness of current policies. [35]

Interviews for case study C, network planning for the electricity distribution networks, were carried out between December 2022 and February 2023 with fourteen expert interviewees identified from desk-based research reviewing the changing frameworks related to electricity network planning. Each of the organisations that had a role in designing or implementing the new frameworks for energy network planning was identified and the person within that organisation contacted. As there are a limited amount of people with expertise in this area, this limits the number of people to interview. However, the interviewees covered all domains of those involved with the changing planning practices. Semi-structured interviews of approximately one hour discussed the need for the introduction of the new planning processes, how the planning approach has been standardised, how consumer data was used and interpreted and the benefits and challenges of the new approach.

The interview data for all three case studies was transcribed, anonymised and thematically coded using NVivo, a coding software application for qualitative research. Due to the sensitivity of the data, the data collected is not available for further access. Codes were developed independently for all three case studies based on iterative analysis of dominant themes, and the research priorities of each case study, as outlined above. Data from the three case studies were presented and discussed at UK Energy Research Centre meetings involving representatives from various universities and across various disciplines. These discussions identified common overlaps and challenges across case studies relating to energy planning practices. To understand these issues more fully, each case study reviewed the data gathered from the case studies using the following three questions as a means to structure our analyses and provide common points of reference across our three areas of work:

1. How has local and regional energy planning evolved in GB since 2019?
2. What are the most significant outcomes of these practices, including challenges to meeting the net zero targets?
3. What new alignments of national, regional and local energy planning and governance are emerging and what tensions might limit further embedding?

Analysis of these questions was discussed during three further UK Energy Research Centre project meetings during the autumn and winter of 2023–4, which explored the implications for the acceleration of local and regional energy systems and to identify any supporting conceptual arguments.

4. Case studies

The sub-national governance of energy systems is complex in GB. The devolved governments of Scotland and Wales hold significant powers over some elements of the energy system, particularly relating to buildings and energy demand, but powers over energy regulation, licensing and tax are largely retained by the UK Government (see [31] for a fuller discussion of GB devolution and energy). The size and powers of local governments varies considerably across GB, but sub-national governments hold few powers and responsibilities relating to energy systems and decarbonisation. To date industrial decarbonisation policy has focussed on six mega-clusters of heavy industry, however half of UK industrial greenhouse gas emissions come from dispersed sites, sited outside of clusters [38]. DNOs plan, operate and maintain regional electricity networks as regulated entities, with six DNO licence areas across GB (Northern Ireland is regulated separately and forms part of the Irish energy system). To date industrial decarbonisation policy has focussed on six mega-clusters of heavy industry, however half of UK industrial emissions come from dispersed industrial sites sited outside of clusters (HM Government, 2021). Case studies of local government-led energy planning, dispersed industrial sites, and electricity distribution networks were selected to represent the interlinking governance dynamics of local and regional systems. Maps of the political geography of the UK, the dispersed industrial sites and the DNO licence areas are provided in Appendix I.

4.1. Case study A: local government-led energy planning

4.1.1. Background

At UK Government level, high-level references to the benefits of 'Local Energy Systems' and a 'place-based approach' to decarbonisation are common [39–41] but formal structures for systematic local and regional energy planning, outside the regulatory framework for electricity and gas distribution companies, are lacking. GB local governments have few formal roles in energy system planning but are nevertheless increasingly developing cross-vector energy decarbonisation plans, and often have ambitious net zero commitments. They also have directly relevant responsibilities, notably transport and spatial planning, although these responsibilities do not necessarily align with clean energy goals. Arrangements for governance of clean energy planning have, however, been uneven, with limited coordination across scales of government, and some significant differences between England, Scotland and Wales, alongside common challenges and questions.

Approaches to local government-led energy planning vary but can be broadly defined as multi-actor processes which develop options for long-term decarbonisation of energy systems in a locality, based on data-led scenarios [42,43]. Guidance commissioned by the UK government recommends a structured process that incorporates robust local data and evidence, a transparent, consensus-based process with local stakeholders, consideration of multiple decarbonisation scenarios, and a process for agreeing next steps and resolving uncertainty [44].

4.1.2. Planning framework

Local Area Energy Planning (LAEP) has emerged as the most prominent approach to local government-led, whole-system, energy planning in GB [45]. The concept of LAEP was initially developed in England and Wales by the Energy Technologies Institute (ETI),[2] and subsequently the Energy Systems Catapult (ESC),[3] as part of the Smart Systems and Heat (SSH) programme (2011–2019). SSH aimed to '*build the foundations for a market-led approach to decarbonise heat across the UK*' [46,47]. A central aspect of the programme was development of the EnergyPath Networks cost optimisation model, a software tool to support local area planning of cost-effective clean energy solutions for heat in buildings, which was tested in three local areas (Bridgend, Bury and Newcastle).

The learning from these pilots was developed into a framework for LAEPs described as providing a seven stage '*localised whole energy systems roadmap to decarbonisation*' (Fig. 1) [48]. The ESC offers consultancy support across the seven stages; this includes baselining the local area (stage 3) across demand, generation, storage and distribution assets, on-street electric vehicle charging potential, building stock and social factors, such as fuel poverty; and utilising their EnergyPath tool in stages 4 and 5 to model and optimise decarbonisation scenarios. Increasingly other large consultancies are offering LAEP support across all stages of the process.

There is no statutory requirement in England for local governments to complete LAEPs, however an increasing number have opted to develop plans. In Wales, the Welsh Government committed to '*all areas of Wales have a detailed local energy plan by the end of 2023–24*' [50] and provided all local governments with funding for technical support to prepare LAEPs. In Scotland, local governments are legally required to prepare Local Heat and Energy Efficiency Strategies (LHEES) and plans [51]; area-based plans for decarbonising heat and improving energy efficiency in buildings. However, LHEES do not incorporate energy supply, transport, or waste and several Scottish local authorities are also preparing whole-system, LAEP-style analysis. The Energy Systems Catapult indicates that 66 local governments[4] across the UK had undertaken, or were undertaking, Local Area Energy Planning by mid-2023 [45].

In addition to local government efforts to structure local energy planning through LAEPs, some local governments have sought to establish their own governance frameworks. Often these were influenced by availability of central government energy innovation funding, for example in the West Midlands where innovation funding[5] was utilised to explore the concept of a Regional Energy Planner role, and in Greater Manchester where funding was used to develop LAEPs for all ten local governments of the combined authority area. These governance innovations were shaped by the availability of central government funding, but also represent a strategic use of funding, which tended to be framed around scalable business model innovation. Instead, these projects aimed to develop further clean energy governance capabilities at the local and regional level. Such governance experiments were particularly prevalent in England where the framework for local energy planning is least structured, indicating that at least some local and regional authorities were seeking to fill this governance gap.

4.1.3. Outcomes of local government-led energy planning

All local governments interviewed who had prepared local plans indicated that the process had been productive in developing new energy system knowledge within the organisation, had helped to build relationships with key stakeholders (particularly DNOs), and provided a framework to prioritise technologies on an area-by-area basis. Wider stakeholders tended to be supportive of local government leading on local energy planning due to their local knowledge, ability to convene cross sector actors and ownership of other key planning strategies such as local transport plans and local development plans.

Despite this, governance of local area energy planning was widely perceived to be fragmented and underdeveloped with many local government officers, consultants and DNOs suggesting that "*Government needs to come up with a standardised process for LAEPs*" (local government officer). Interviews across local government, industry and consultancies emphasised how the lack of a consistent and coordinated approach to local energy planning is resulting in diversity in approach between different areas, limiting the ability of other actors, such as DNOs or industry, to have regard to LAEPs in their business planning.

One of the clearest common challenges in undertaking local energy planning and delivery was related to capacity and capability within local authorities. A Welsh local government officer suggested that most authorities "*know how much we need to do. But at the same time, local authorities just don't have any capacity*". Limited funding to appoint technical consultants and employ council staff to lead planning often resulted in short-term contracts with associated concerns that staff and skills would not be retained. Similarly, most areas conducting LAEPs commissioned consultants to develop the technical modelling and scenarios. This modelling was provided on a proprietary basis and, while relationships with consultant teams were valued, many areas expressed concern over the lack of open access to modelling outputs and frameworks, leading to difficulty in testing assumptions and refreshing plans. These challenges led several interviewees to express concerns that LAEPs would become "*just another strategy*" (local government officer) or a "*plan on the shelf*" (consultant). Specifically, that the lack of access to models and data sources could lead to a "*black box document is not really worth the paper it's written on*" (local government officer).

An additional delivery challenge relates to mobilising the significant investment LAEPs indicate will be required to deliver local decarbonisation. Many of the delivery priorities identified in LAEP relate to either complex technical projects such as heat networks, or to policy areas that are largely dependent on national funding and regulation, such as

[2] A public-private partnership to accelerate the development of low carbon technologies.

[3] Part of a network of nine technology and innovation centres, the ESC aims to support innovation across the energy system.

[4] This equates to 18 % of UK councils

[5] Prospering from the Energy Revolution

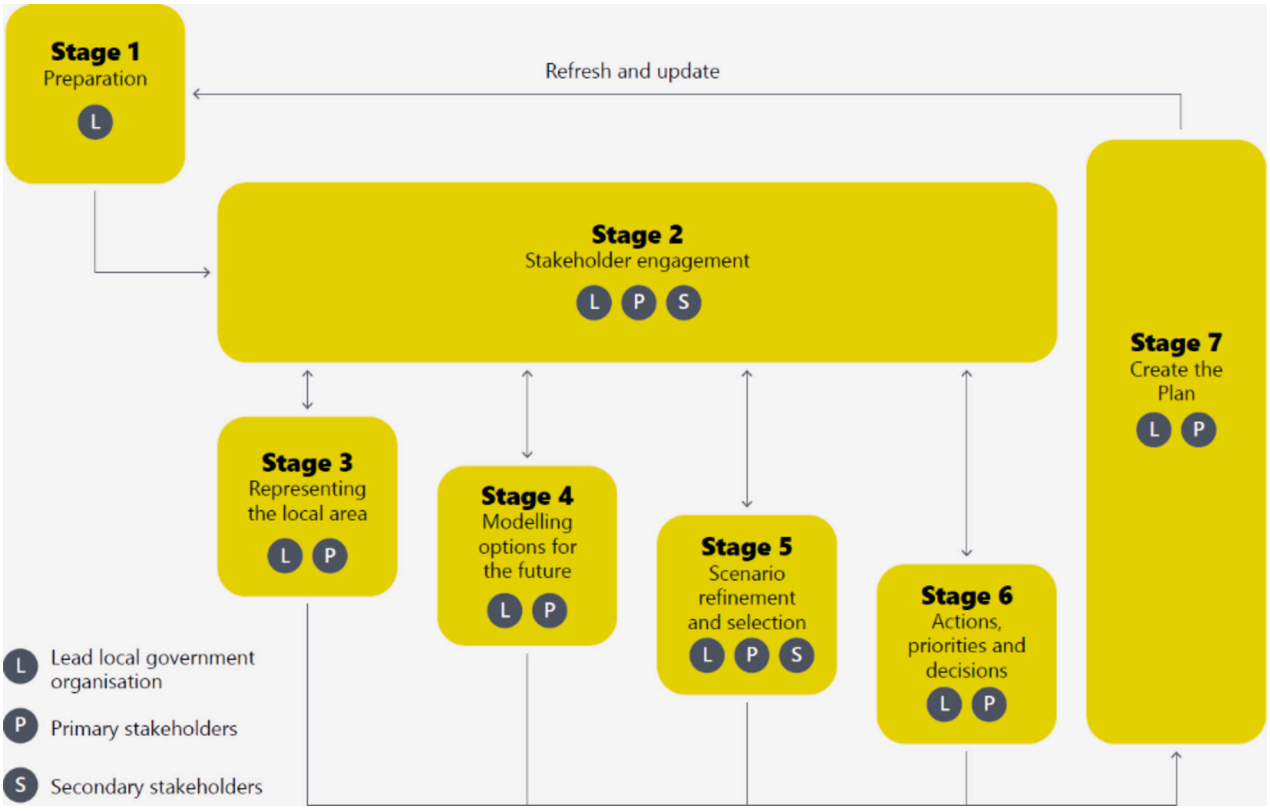

Fig. 1. Local Area Energy Planning stages.
(source Centre for Sustainable Energy and Energy Systems Catapult, 2020).

domestic retrofit or electricity network investment. Local government officers expressed concern about their ability to mobilise the skills and funding to develop the large number of priority projects towards deployment, or to influence the policy landscape in support of delivery. While an increasing number of energy efficiency and heat decarbonisation funding schemes, particularly aimed at the public sector estate, have been allocated to local government, this tends to be through competitive funding rounds and funding is not yet commensurate with deployment scenarios indicted in LAEPs. Additionally, the relatively short-term nature of such funding has required local governments to be reactive to funding as it was announced, undermining strategic approaches to energy planning and requiring considerable resources for bid preparation.

Local government in England has faced very challenging financial circumstances in recent years with significant real-terms funding cuts since 2010 [52]. Many local governments reported that the LAEP process provided a clear picture of the "*scale of the challenge*" and was focussing local government action on how to mobilise private investment into local climate action. Many were utilising LAEPs to develop pipelines of public sector projects that could be packaged into portfolios attractive to investors. There was, however, acknowledgement that the LAEP process is only a first step in the project pipeline development with considerable additional resources required at the local level. As one local government officer highlighted "*Delivery is going to be a much bigger resource challenge than development of the plans*". These efforts to coordinate local net zero investment programmes therefore tended to be in areas with additional capacities and resources, such as Combined Authorities.[6]

The final delivery challenge for local government-led energy planning relates to clarity on how local plans relate to planning at other scales. There is no consistent framework for local government action on energy system decarbonisation across GB and, as described by the Climate Change Committee, it '*remains unclear how central, devolved and local government will operate coherently towards the Net Zero goal*' [53].

4.2. Case study B: decarbonisation of dispersed industrial sites

4.2.1. Background

In the UK, action on industrial decarbonisation has been led at the national level by the Department for Business, Energy and Industrial Strategy (BEIS) and its successor, the Department for Energy Security and Net Zero (DESNZ). Policy goals and strategies have evolved rapidly from problem exploration to implementation since 2019 [54]. Funding has come through four main initiatives. The first is the Industrial Energy Transformation Fund, which supports site-level projects by offering grants for feasibility studies, engineering studies, and the deployment of industrial energy efficiency and deep decarbonisation projects. The remainder of the funding takes a local approach. Initially, efforts focused on the six 'mega' clusters of energy-intensive industries that together account for just over half of the UK's industrial emissions [38]. These

[6] Combined Authorities are a form of devolved government in England whereby multiple local governments in a locality collaborate as part of a legal structure [90]

clusters have received support through two key programmes. The Industrial Decarbonisation Challenge promoted industry collaboration and knowledge sharing across clusters, providing funding for net-zero cluster roadmaps and feasibility studies for shared infrastructure. In parallel, clusters most advanced in carbon capture use and storage (CCUS) development were chosen through a competitive 'cluster sequencing' process to enter negotiations for capital and revenue support through relevant Business Models.

Recently, government attention has broadened to include industrial areas outside the mega-clusters, referred to in policy documents as 'dispersed sites.' However, while planning-based strategies to decarbonise energy-intensive industries are part of government policy, the primary emphasis remains on competition-driven innovation funding, with most of this funding directed towards mega-clusters rather than dispersed sites.

A successful low-carbon industrial transition will require the co-creation of new technologies, social networks, and institutions [54]. Electrification will play a key role with industrial electricity demand forecast to increase by 32 % in 2050 compared to 2020 levels, as the sector transitions away from natural gas and petroleum [55]. Presently, however, local and regional governance for industrial decarbonisation is underdeveloped, with the supporting institutions absent or yet to reach full maturity. This underdevelopment can be linked to the UK's historical adoption of a laissez-faire approach to industrial strategy over the past four decades, during which the Treasury maintained a sceptical stance towards the effectiveness of industrial strategies for fostering growth [56]. Hence, despite having an Industrial Decarbonisation Strategy since 2021, the UK does not presently have an industrial strategy. This absence is reflected in an institutional void. While the Welsh government boasts an arms-length industry body, Industry Wales, both England and Scotland lack a dedicated institution for overseeing industry. At the regional level, planning for industrial decarbonisation has therefore been ad hoc, evolving as mega-cluster initiatives develop capacity from the ground up. Notably, in October 2024, the Labour government introduced a green paper on industrial strategy, potentially signalling a departure from this long-standing hands-off approach.

This new approach offers a chance to address the institutional gaps that have hindered cohesive industrial decarbonisation efforts across the UK. Research on mega-cluster decarbonisation makes it clear that the requirement for clusters to collaboratively develop net zero cluster plans through the Industrial Decarbonisation Challenge has triggered a ripple effect, fostering deeper cross-sector collaboration and the formation of new stakeholder networks [57–59]. Notably, the new cluster networks are larger and more diverse than for previous standalone CCUS projects, with increased involvement from local and regional governments [58]. Although not originally intended as such, the focus on using mega-clusters as a conduit for achieving decarbonisation appears to have spurred local experimentation, providing stakeholders with opportunities to develop regional industrial strategies and institutions that would not otherwise exist.

4.2.2. Planning framework

Until recently, there has been little policy aimed at the decarbonisation of dispersed sites [60] which emit almost half of UK industrial emissions. The result has been growing concerns about emerging inequalities in the decarbonisation opportunities available to these dispersed sites when compared to firms within mega-clusters. As a paper sector representative noted, "*if we were all in clusters, we'd be able to piggyback and benefit from those economies of scale and work but it's difficult, we can't because of our geographical location.*" The potential for disparities has been exacerbated in England by the lack of intermediary institutions to span between national policy and the local industrial base [61], the gap that the Industrial Decarbonisation Challenge has begun to alleviate for mega-clusters.

> "some industries there felt that they were close to becoming a cluster, but there just wasn't the link-up between the local government, national government and so on, and so they didn't become one."
>
> Senior policy officer NGO

To address this issue, in 2023 DESNZ launched the £6 million Local Industrial Decarbonisation Plans (LIDP) competition, which aimed to provide grants to support dispersed sites to form 'local industrial clusters' to develop local decarbonisation plans. The competition has a threefold purpose: firstly, to offer financial support for the development of robust and strategic decarbonisation plans for dispersed sites within local industrial clusters. Secondly, to collect empirical data that could benefit the decarbonisation efforts of other dispersed industrial sites. Finally, to foster collaboration, strengthen skills, augment capacity, and enhance the capability of local industrial clusters in their pursuit of decarbonisation planning [62]. In support of this final aim, the application guidelines avoided providing a strict definition of the term 'industry'. This flexibility allowed a broader range of potential participants to engage with local industrial clusters, creating opportunities for broader resource and energy efficiency initiatives that are presently under-supported in existing policies [60].

The winning entries were announced in 2024 [63] and feature 13 projects from England, Wales, and Northern Ireland, ranging in scale from an industrial estate of five industrial partners to the entirety of Northern Ireland. Consortia members are similarly varied, drawn from across industry, local authorities and consultancies, and several are also members of mega-cluster projects, offering opportunities for knowledge transfer. In principle, LIDPs offer a significant evolutionary step, with the prospect of introducing a new tier of local industrial governance, and a more structured approach to the decarbonisation of dispersed sites through the conduit of local industrial clusters. However, their effectiveness and impact has yet to be judged. The success of these initiatives will require effective engagement with the local industrial base, adaptation to an evolving policy landscape and funding to turn plans into tangible outcomes. One key challenge will be synthesising insights across these projects, given their differences in scale and stakeholder backgrounds, to provide a cohesive approach for the remainder of dispersed sites.

4.2.3. Outcomes of planning for industrial decarbonisation

Planning of industrial decarbonisation remains embryonic with a significant focus on competitive allocation of innovation funding. Industrial decarbonisation will be an ongoing endeavour, entailing large-scale infrastructure projects that typically take several years to complete. Policy support will be crucial to develop new markets for low-carbon goods, and this is likely to be required into the mid-term. Consequently, establishing the outcomes of the UK's approach to local and regional planning for industrial decarbonisation remains a work in progress. While the situation continues to evolve, however, some preliminary observations can be made.

For local industrial clusters, there is a great deal of uncertainty, primarily due to the ambiguity surrounding the definition of what constitutes a local industrial cluster. While the number of mega-clusters in the UK is finite and countable, the number of local industrial clusters is open to question and largely dependent on areas self-identifying. A competitive funding approach that relies on the capacity of local areas to build consortia capable of bidding for, and winning, government funding to create LIDPs, inevitably excludes those areas that, for various

reasons, did not participate or were unsuccessful in their bids. It is encouraging to note that members of mega-cluster networks are now actively involved in bids to develop plans for local industrial clusters [62], suggesting that some learning from the Industrial Decarbonisation Challenge is transferring to new contexts.

Additionally, there are considerable uncertainties regarding integration between local government-led local energy planning and LIDPs. LAEPs were initially developed focussed on decarbonising domestic heating and while industrial and commercial heat is incorporated into modelling, this tends to consider industry as points of demand or as sources of waste heat – without a detailed consideration of the specific process heat requirements of different industries. Decarbonising industrial sites will rely on a complex interplay between bespoke decarbonisation technologies and the availability of energy network infrastructure. This will require network planning to develop ways to incorporate long-term shifts in the energy needs of specific industries. In the absence of a regional tier of governance providing coordination, it remains unclear how existing industrial initiatives can scale up to deliver a whole sector industrial transition. If this is not possible then we are left with the pivotal question of if, and how, we decarbonise the industrial areas that are left behind. And if we do not decarbonise them, then what are our plans for these places?

4.3. Case Study C: introduction of strategic planning for the electricity distribution networks

4.3.1. Background

In GB, electricity and gas distribution networks operate as regulated monopolies, with networks awarded a revenue allowance prior to each price control period, currently five years, known as RIIO.[7] The amount of money awarded to the network company is decided through a price control process whereby the companies submit a business plan to Ofgem that contains their projected costs to operate and maintain the business and to meet outputs set by Ofgem for the upcoming price control period. The design stage provides the framework for the business plans that the companies will need to follow.

Since 2010, the business planning frameworks have undergone an evolution, with the network companies being incentivised to include customer and stakeholder input into the planning process [64]. This was partly due to the network companies being overly focussed on the regulator rather than their customers but also as a response to more distributed generation and other demand side resources being connected at the distribution level (ibid). The most recent electricity distribution price control framework has again increased the amount of customer representation, with the introduction of a new, standardised planning framework for load related expenditure (LRE) to attempt to incorporate the large amount of uncertainty related to the possible pathways to net zero.

4.3.2. Planning framework

Traditionally, load related expenditure (LRE) planning has been a reasonably simple affair using engineering justification papers to request revenue for major improvement works. During the consultation process for RIIO ED2,[8] working groups were convened to discuss the best approach to include local energy planning in the price control frameworks and to reflect LAEPs and other regional priorities from devolved and local governments [65]. Further explorations by various Ofgem working groups on a localised approach to planning showed a need to standardise processes.

Prior to the start of RIIO ED2 in 2023, Ofgem and the Energy Networks Association (ENA) gradually introduced a suite of standardised planning tools to model possible scenarios and include known investments to create a range of pathways on which to base their future costs (Fig. 2) [66–72].

In conjunction with the networks' industry group, the ENA, and the energy regulator, Ofgem, the DNOs agreed to a standardised framework for a distributed version of the centralised Future Energy Scenarios (FES) [73], known as the Distributed Future Energy Scenarios (DFES) [68]. The DFES are developed every two years, using the FES, and disaggregated to an electricity supply point level. Due to a current lack of in-house capability in this type of assessment, consultancies are employed by the networks to disaggregate the data available from the FES (interviews, system forecasting engineers). The DFES are expected to be compliant with the legislated Carbon Budgets, and in combination with postcode and financial data, and annual consumer and stakeholder engagement, the consultancies produce a regionalised view of the numbers of low carbon technologies (LCTs) expected on particular parts of the network for each pathway (interview, consultancy plus [74]). The DFES also include an assessment of local energy plans, using a checklist developed during meetings of the Overarching Working Group [65]. Other developments impacting on the electricity networks are also included in the DFES, such as industrial development, housing and distributed generation (Fig. 3).

The distribution network interviewees explained how they use numbers of expected LCTs, converted into amount of required capacity in conjunction with historical trends to highlight any capacity issues over the DFES scenarios in the Network Development Plan (NDP). As part of the NDP, for benchmarking purposes and as a planning tool, the networks produce a 'best view' of the most likely scenario pathway for their area. This could be a DFES pathway or a new separate pathway. As described by a network representative "*the best view scenario is by no means to say a common one, but it's a framework which allows certain level of customisation for each DNO to represent their individual license area, but use a similar construct such that there is a sense of comparison*". Optioneering is a method used to decide the optimal approach to providing solutions to upcoming network challenges, such as capacity issues. Optioneering uses a flexibility first approach via the Distribution Network Options Assessment (DNOA) where a Common Evaluation Methodology (CEM) [71] is applied to understand whether any issues could be rectified or delayed using flexibility services, such as demand side response, or if traditional reinforcement would be a preferred solution [76]. The optioneering approach also incorporates uncertainty by showing a business-as-usual (BAU) expenditure and an uncertain expenditure [77]. Networks are then able to use this process to evidence a pathway where strategic investment would be economically beneficial to consumers.

The LRE plan would be expected to incorporate uncertainty from the forecasts by giving a baseline forecast, such as the best view developed for the NDP, as well as a possible but more uncertain view, including a justification of where an uncertainty mechanism may be required. This baseline also then allows Ofgem to be able to compare and contrast across the DNOs, as a benchmark. The DNOs were also expected to use the forecasts to include justification of any strategic investment.

4.3.3. Outcomes for electricity network planning

Overall, the change in approach to the use of modelling as a planning tool was welcomed by DNO, trade body and regulator interviewees, as this has allowed the DNOs and Ofgem to consider future proofing the distribution networks through strategic investment i.e. investment ahead of need, something that was only allowed in previous price controls for an expected increase in demand but not for generation connections [77]. However, what standardising the planning processes illustrated was just how variable the uptake of LCTs is likely to be, not just across, but also within, licence areas and companies.

For some DNOs, working with local government also entailed

[7] RIIO stands for Revenue = Innovation + Incentives + Outputs and companies earn revenue by using innovation to achieve incentives across a range of outputs.

[8] ED2 is the electricity distribution network price control period from 2023 to 2028.

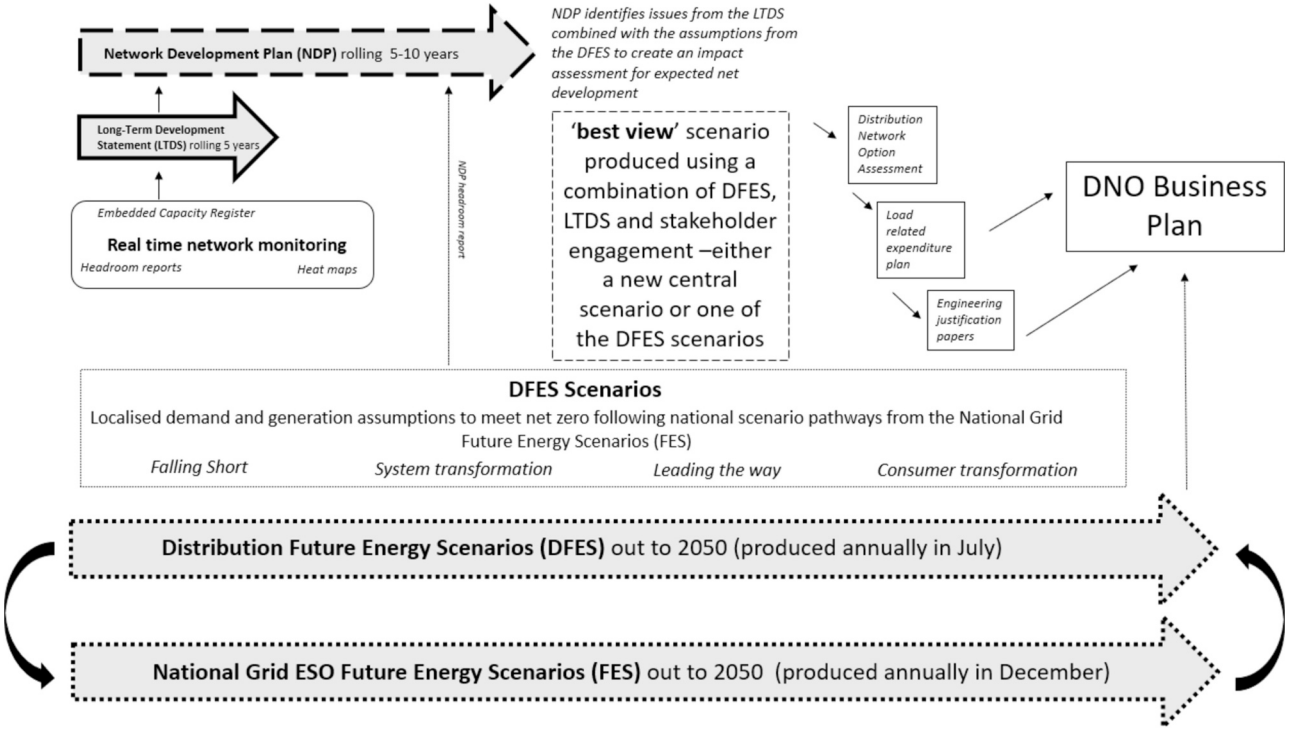

Fig. 2. Suite of planning tools for RIIO ED2 and further strategic investment (source: author).

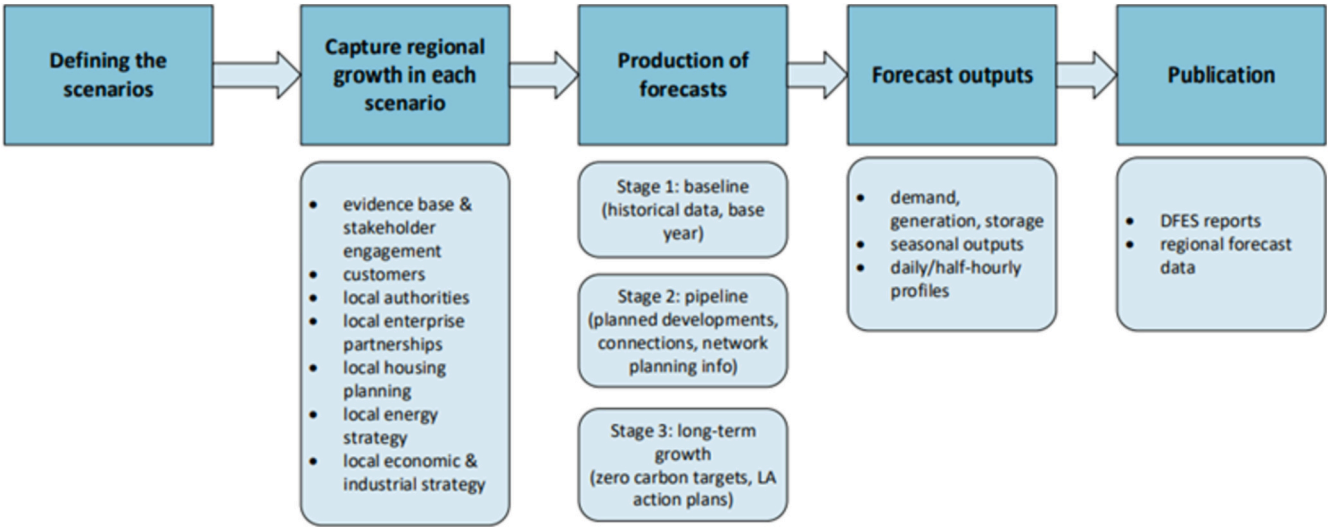

Fig. 3. Common DFES methodology framework as agreed by the six DNOs and NGESO. (source: [75]).[a]
[a]This framework was an output of the ENA's Open Networks workstream 1B product 2.

working with other electricity and gas distribution and transmission companies, as local government boundaries and DNO licence areas are not aligned. In some instances, interviewees suggested that this was supporting a more integrated, whole system approach to both local energy planning and the DFES. However, the centrality of DNOs as sources of information in local government-led planning, particularly where only one network is providing input, risks them dominating the process at the expense of alternative views of decarbonisation.

Another consequence of customer focussed planning that was highlighted by all the network companies interviewed, was the difficulty of incorporating the needs of local government. A checklist had been developed by the Ofgem working groups to assess local energy plans, and although the DNOs were in most cases involved in some form in local energy planning, there was a capacity gap between the ambition in

local energy plans compared to the ability to deliver them. Much of this was due to limited funding and capability within the local authorities, something also highlighted in Section 4.1.1. There was also the acknowledgement that a further challenge was "to *understand, to improve also the local councils, the local authorities, understanding of their role in local area energy plans*" (interview, network).

In response to this uncertainty, and the acknowledgement from Ofgem that "*we very quickly realised it was going to be quite difficult to set allowances consistently for all the DNOs given all of their different scenarios*", Ofgem introduced uncertainty mechanisms, including reopeners for changes to policy, and volume drivers to allow the revenue to flex to meet possible future requirements [78]. However, it is still too early to say if these types of mechanisms provide the optimum solution to network investment that will be required for local and regional decarbonisation.

5. Cross case analysis

Case studies A and B make common appeals to the convening power and democratic mandate of local government in negotiating competing interests in energy system change, although specifics on how local government do these complex tasks is lacking. There are, however, differences in framing and delivery across the case studies. High-level industrial decarbonisation policy highlights the role of local spatial planning, but in practice activity is focussed on mobilising local action coalitions to access short-term competitive funds. Local government-led planning approaches endeavour to create long-term cross-sector pathways to net zero which identify interactions between sectors and vectors. However, these approaches are often limited by national policy uncertainty (for example funding for retrofit or the role of hydrogen in heating) and the need to identify specific short-term priorities to attract 'competitive' international finance and mobilise investment. Pursuing competitive funding for decarbonisation can therefore serve to undermine the aims of planning to provide long-term and cross-vector coordination. This uncertainty is then reflected in the DNO planning, where uncertainty mechanisms need to be applied due to, amongst other drivers, a lack of knowledge of the delivery of local energy planning or decarbonisation of dispersed industrial sites, but which may lead to inadequate customer outcomes should the timing of network investment be sub-optimal. LAEPs, LIDPs and electricity distribution network planning are all emerging approaches, with each attempting to configure relationships between actors and frame the problems that energy planning can help solve.

Our analysis indicated that many of the acceleration conditions outlined by Roberts and Geels [16] are beginning to emerge for local and regional energy systems in GB. Shifting public opinion (e.g. through climate emergency declarations [29]), technological change (e.g. the uptake of LCTs [79]) and the mobilisation of new actors and networks (e.g. new interactions between DNOs, local government and industry in local energy planning) are starting to support political acceleration for more integrated local and regional energy systems. However, this is manifesting in a proliferation of approaches to local energy planning with a lack of alignment between local government, DNO and industry approaches. Much of the policy activity in this space also focusses on testing and experimenting with new approaches to local energy planning, with less evidence of purposive policy efforts to reconfigure decentralised energy policy or coordinate across actor groups. Our findings, therefore, suggest that the presence of Roberts and Geels [16] three conditions for political acceleration may be insufficient for acceleration to occur, if the dynamics of differing user-types, as defined by Schot et al. [8] are also not considered. Specifically, it could be argued that while acceleration conditions are being met, acceleration is being delayed due to policy not consistently targeting user-intermediaries within each sector, thereby leaving aspects of local and regional energy systems operating at different stages of the experimentation to acceleration process.

Our findings emphasise the importance of user-intermediaries - with local governments, DNOs and industry groups all seeking to shape approaches to envisioning, modelling and planning local energy systems. While the current period of experimentation in approaches to local energy planning are developing new relationships between decentralised actors, the lack of a policy framework that coordinates user-intermediaries in a consistent way has resulted in varied approaches across the country. DNO planning is the most structured and institutionalised, but there is limited evidence of LAEP influencing material developments and LIDPs are at too early a stage to gauge their influence over other processes.

However, the electricity networks provide an example of how a user intermediary can be targeted. Frameworks designed by Ofgem in conjunction with the Energy Networks Association (e.g. [68]) for future planning have provided standardised processes across the separate companies. This enables strategic planning of the electricity distribution system and methods to incorporate, and therefore accelerate, local government and local decarbonisation plans. However, the introduction of this process is still in its infancy with challenges in its implementation due to a focus on a single sector and as such there are questions to be resolved around how these plans will integrate with whole system planning. A further challenge is the lack of policy focus on user-intermediaries in local government and dispersed industrial sites; this creates further tensions as there is limited ability for local energy planning to be delivered. This lack of consistent policy across user intermediaries in local and regional energy systems has created a situation of imbalance where energy planning has entered into a chicken or egg situation whereby decarbonised systems require network capacity or flexibility revenues to be viable but DNOs can only fund network development once there is certainty of demand and technology deployment. Addressing this issue is a central challenge for energy planning coordination going forward.

The case studies provide evidence of governance processes that have encouraged niche experimentation through a renewed emphasis on the role of local energy planning in energy system change. However, the forms of energy planning being developed across local governments and industry vary, remaining relatively peripheral for the UK Government, with priorities, roles and responsibilities poorly defined. While processes to conduct systematic local energy planning at the electricity distribution level have become more structured, the lack of a formalised role for local governments, or for dispersed industrial sites, in wider, whole-system planning has limited the acceleration of coordinated change at the sub-national level. Additionally, reliance on short-term and competitive funding at local government and industrial level results in fragile actor networks who often must reconfigure priorities to meet funding availability.

6. The introduction of Regional Energy Strategic Plans

In GB, legislation in the Energy Act 2023 aims to deliver on the decarbonisation commitments made by the UK government in the Energy Security Strategy [80], The Ten Point Plan [81] and the Net Zero Growth Plan [82]. It includes increased direction-setting, information and financial assistance powers for government and creates a new entity, the National Energy System Operator (NESO), an independent body to coordinate a whole system approach to ensuring energy security,

including through system operation and planning, and to act as an advisor to the government and regulator on strategic direction to achieve net zero [83]. Included within these updated powers is a new mandated duty for the energy regulator, Ofgem, to protect existing and future customers' interests by supporting compliance with the Climate Change Act 2008, amended 2019, through meeting the Climate Change Committee's carbon budgets and the UK's 2050 net zero target [84]. This has committed Ofgem to a 'Net Zero' duty, so requiring the DNOs to ensure their investments are compatible with a net zero outcome, with an anticipated infrastructure investment requirement of £300-£340bn [85].

Ofgem have subsequently published a decision to introduce a new function - Regional Energy Strategic Planning (RESP) - to support coordination between vectors and scales [33,86]. Although the role, remit and boundaries of the RESPs are not yet finalised, the RESPs will be developed by regional arms of the NESO and will be regional whole system plans that will guide future planning and strategic investment in the energy networks. The RESPs are also aiming to fill a regional governance gap, mediating between the national and local aspects of the physical system.

Ofgem are currently exploring how the strategic plan will be produced and the processes required to integrate current planning practices. Significantly, much of the progress on local energy planning is from a technocratic perspective with organisations such as the energy regulator, DNOs, and the new independent system operator (NESO) leading reforms to local energy planning processes, which are therefore directed towards the infrastructure needs of the transitioning system. However, these debates are being led by the energy regulator rather than national political organisations (government departments responsible for net zero or local government), suggesting a reluctance from national government to connect the decentralisation of energy planning to broader multi-level governance reforms.

7. Conclusions

This paper sought to provide evidence on the current governance and practices of local and regional energy planning in GB, and to comment on evolution, outcomes and tensions in regard to accelerating transitions for GB's net zero goals. As Torrens et al. [7] note, there is a lack of evidence on how efforts to transform urban governance and planning regimes are failing or succeeding to mobilise action towards sustainability. Although the case studies we present cover local and regional systems, rather than just the urban environments as explored in Torrens et al.'s [7] research, the evidence we provide shows that, even in this wider environment, experimentation is taking place but that further political action is required at a local and regional level to accelerate these initial experiments towards mainstream transitional changes.

Acceleration conditions create space for political acceleration, but require coherent policy targeted at user-intermediaries to create the rules, regulations, processes and structures to accelerate beyond experimental niche technologies and practices, and through which a decarbonised system could be configured. This research has highlighted the need to target *all* user-intermediaries at a local and regional level to create this coherent policy landscape. The current institutional focus on solving problems by targeting only one user-intermediary through changing the network planning architecture rather than targeting user-intermediaries within *all* areas of local and regional system planning has created an uneven acceleration process. This lack of policy consistency across all aspects of local and regional energy systems creates further uncertainty for strategic planning processes, with the lack of a mandate for local government a major issue.

The multiple reviews and consultations[9] on the future of the GB's economic regulation and governance of the energy networks and markets have still not resolved this lack of consistency or lack of a mandate for local government, creating a 'governance gap'. Although the frameworks for the Regional Energy Strategic Plans are still to be finalised at time of writing, the introduction of a new strategic planning approach may assist with infrastructure planning. However, there is still only limited focus on LAEPs and LIDPs, insofar as the strategic planning role will provide a one-stop shop for information on local energy planning. We suggest that targeted policy is required that focusses on *all* user-intermediaries across local and regional energy systems to gain the capacity needed to deliver the decarbonisation objectives required at this level. Without this, the ability of local and regional energy systems to accelerate beyond experimental niches is limited, which may make meeting the net zero target reliant on large-scale centralised technology, which while benefitting the incumbent, may prove expensive for the consumer. (e.g. [87]).

CRediT authorship contribution statement

Helen Poulter: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jess Britton:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Imogen Rattle:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ronan Bolton:** Writing – review & editing, Validation, Methodology, Conceptualization. **Jan Webb:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Peter Taylor:** Writing – review & editing, Formal analysis, Conceptualization.

Declaration of competing interest

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

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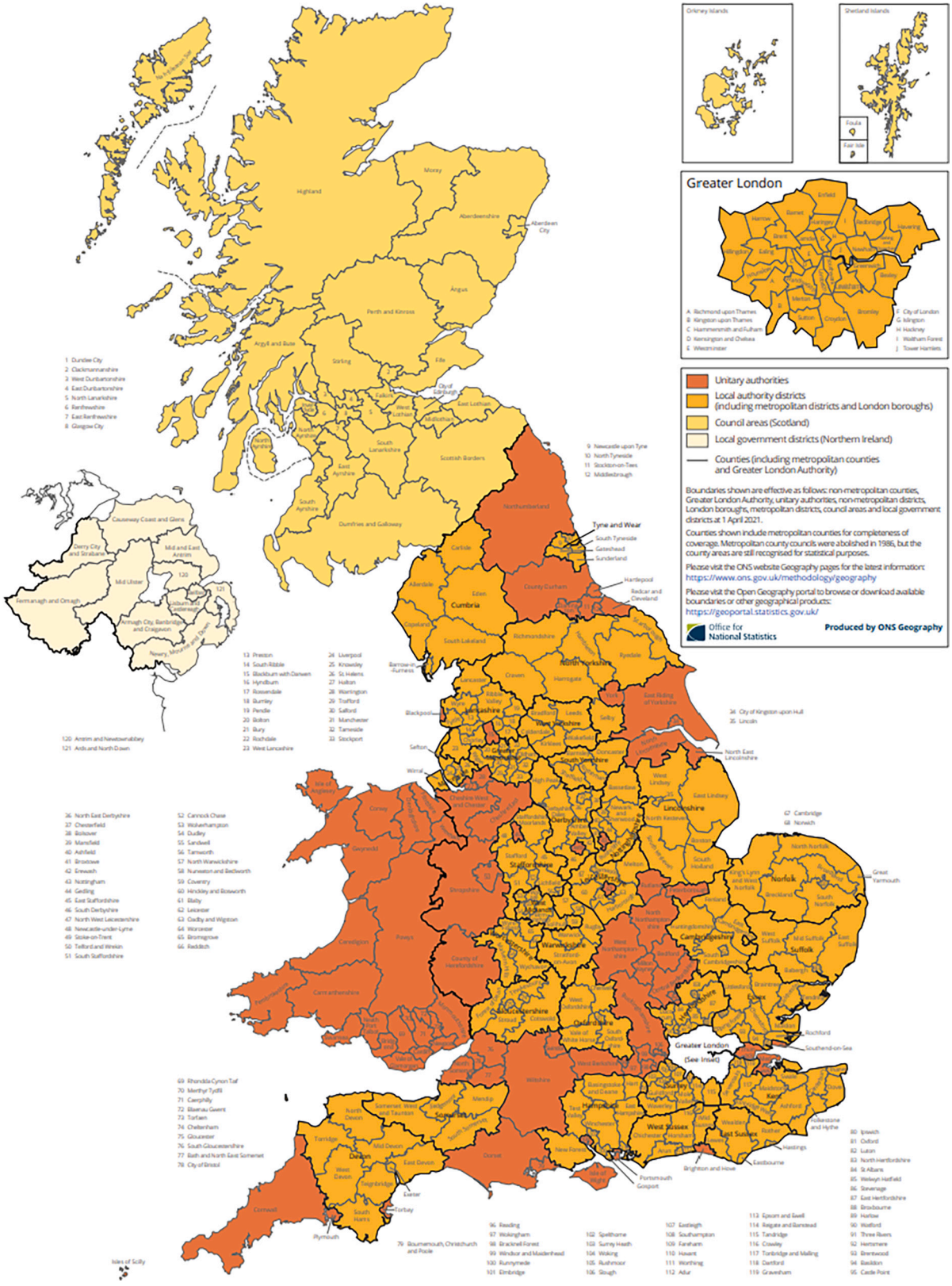
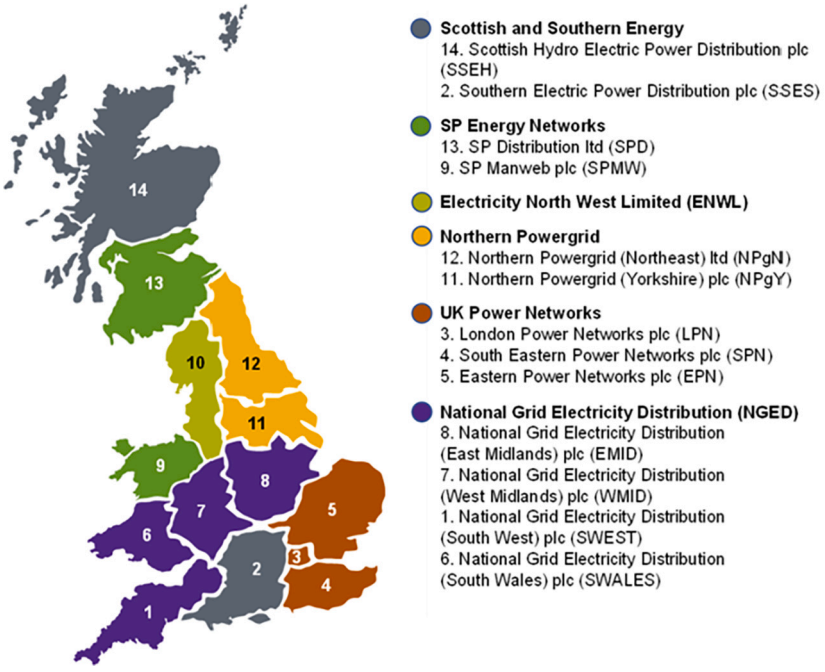
[9] The Future of Local Energy Institutions and Governance [86], Future Systems and Network Regulation (FSNR) [91] The Future of Distributed Flexibility [92] and the Review of Market Arrangements (REMA) [93]

Appendix I



Local Government: District, County and Unitary Authorities (April 2021) Map in United Kingdom (source [88]).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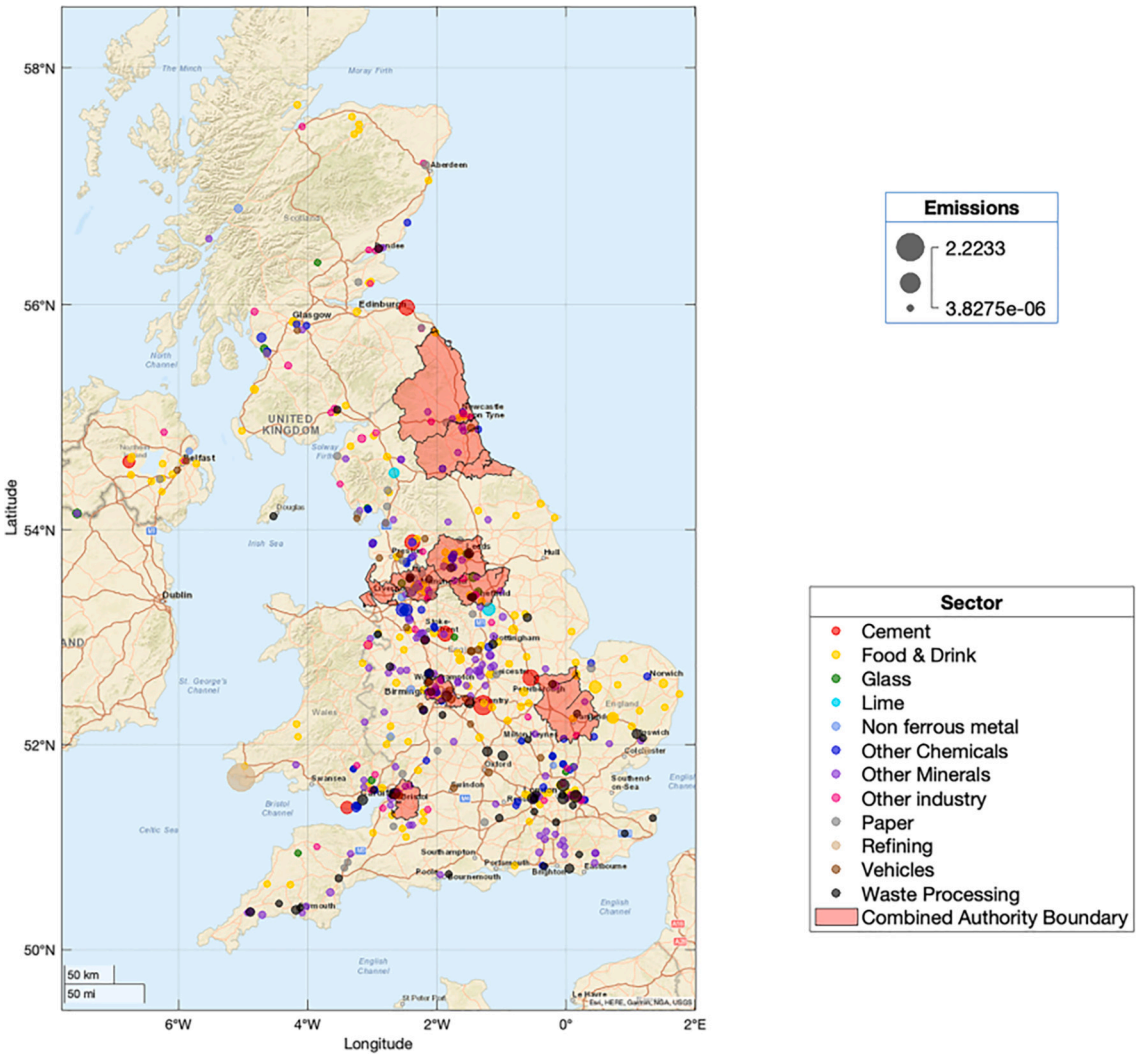
1
Scottish and Southern Energy
14. Scottish Hydro Electric Power Distribution plc (SSEH)
2. Southern Electric Power Distribution plc (SSES)
SP Energy Networks
13. SP Distribution ltd (SPD)
9. SP Manweb plc (SPMW)
Electricity North West Limited (ENWL)
Northern Powergrid
12. Northern Powergrid (Northeast) ltd (NPgN)
11. Northern Powergrid (Yorkshire) plc (NPgY)
UK Power Networks
3. London Power Networks plc (LPN)
4. South Eastern Power Networks plc (SPN)
5. Eastern Power Networks plc (EPN)
National Grid Electricity Distribution (NGED)
8. National Grid Electricity Distribution (East Midlands) plc (EMID)
7. National Grid Electricity Distribution (West Midlands) plc (WMID)
1. National Grid Electricity Distribution (South West) plc (SWEST)
6. National Grid Electricity Distribution (South Wales) plc (SWALES)

Distribution Network Operators (DNOs) and their licence areas in 2023 (source: [89]).



Location of the UK dispersed sites by sector and emissions in MtCO2e mapped against Combined Authority areas (source: [35]).

Appendix II

Interviewees for case study A: local authority energy planning (N = 47).

Stakeholder type	Organisation	Case study location	Date
Combined Authority officer - energy	Greater Manchester Combined Authority	Greater Manchester	Mar-23
Combined Authority officer - data	Greater Manchester Combined Authority	Greater Manchester	Mar-23
Local Authority officer	Manchester Council	Greater Manchester	Apr-23
Local Authority officer	Manchester Council	Greater Manchester	Apr-23
Local Authority officer	Manchester Council	Greater Manchester	Apr-23
NGO - energy	Carbon Coop	Greater Manchester	Mar-23
NGO - energy	Carbon Coop	Greater Manchester	Mar-23
Energy Consultant	Independent Consultant	National	Jun-23
DNO - flexibility markets	Electricity North West	Greater Manchester	Mar-23
DNO - network planning	Electricity North West	Greater Manchester	Mar-23
Industry - heat networks	Civic Quarter Heat Network	Greater Manchester	Mar-23
Consultant - heat networks	Independent Consultant	Greater Manchester	Mar-23
Local Authority officer	Oldham Council	Greater Manchester	Apr-23
Combined Authority officer - energy	West Midlands Combined Authority	West Midlands	Sep-23
Combined Authority officer - energy and data	West Midlands Combined Authority	West Midlands	Mar-23

(continued on next page)

(*continued*)

Stakeholder type	Organisation	Case study location	Date
Local autrhority officer - energy projects	Coventry Council	West Midlands	Sep-23
Consultant - integrated energy systems	Engie	National	Oct-23
Academic - Birmingham Energy Insitute	University of Birmingham	West Midlands	Nov-23
Academic - energy innovation projects	University of Birmingham	West Midlands	Oct-23
Industry	Webster and Horsfall	West Midlands	Sep-23
DNO - stakeholder engagement	National Grid Electricity Distribution	West Midlands	Nov-23
DNO - network planning	National Grid Electricity Distribution	West Midlands	Nov-23
Consultant - energy data	Advanced Infrastructure	National	Nov-23
Local Authority officer - Climate and energy	Fife Council	Fife	Apr-23
Local Authority officer - LHEES	Fife Council	Fife	Nov-23
DNO	SP Energy Networks	Fife	Aug-23
Local Authority officer - LHEES	Dundee Council	Scotland	Aug-23
Local Authority officer	Perth and Kinross Council	Scotland	Sep-23
Local Authority officer	Perth and Kinross Council	Scotland	Sep-23
Local Authority officer	Fife Council	Fife	Apr-23
Consultant - local energy planning	Arup	National	Sep-23
Consultant - local energy planning	Arup	National	Sep-23
Community NGO	Greener Kirkcaldy	Fife	Aug-23
Engagement officer and engineer	Off-shore Renewable Energy Catapult (OREC)	National	Nov-23
Regional Authority officer	Cardiff City Region	Cardiff Capital Region	Jan-24
Regional Authority officer	Cardiff City Region	Cardiff Capital Region	Jan-24
Local Authority officer	Ceredigion Council	Mid Wales	Jan-24
Consultant - community engagement	Afallen	Cardiff Capital Region	Jan-24
Public Sector consultant	Local Partnerships	Across Wales	Jan-24
Public Sector consultant	Local Partnerships	Across Wales	Feb-24
Local Authority officer	Swansea Council	Cardiff Capital Region	Jan-24
Government officer - Energy Directorate	Welsh Government	Wales	Jan-24
Local Authority officer	Bridgend Council	Cardiff Capital Region	Jan-24
Local Authority officer	Bridgend Council	Cardiff Capital Region	Jan-24
Local Authority officer	Newport Council	Cardiff Capital Region	Jan-24
Regional Authority officer	Cardiff Capital Region	Cardiff Capital Region	Jan-24
DNO	National Grid Electricity Distribution	Cardiff Capital Region	Nov-23

Overview of semi structured interview expert respondents on industry (N = 30).

Pseudonym	Stakeholder type	Date of interview
Site manager, Bradford	Local industrial decarbonisation initiative	Jul-21
Senior manager, Bradford	Local industrial decarbonisation initiative	Aug-21
Repowering the Black Country	Local industrial decarbonisation initiative	Aug-21
Representative, UK Steel	Sector and employee organisations	Aug-21
Growth manager, Bradford	Local authorities	Aug-21
Director of Cement	Sector and employee organisations	Aug-21
Representative, paper sector	Sector and employee organisations	Aug-21
Representative, Community trade union	Sector and employee organisations	Aug-21
Representative, Energy Hub	Local authorities	Aug-21
Representative, ceramics sector	Sector and employee organisations	Aug-21
Local authority officer within West Yorkshire combined authority	Local authorities	Aug-21
Analyst, International Energy Agency	Think tanks and research organisations	Sep-21
Analyst, energy organisation	Think tanks and research organisations	Sep-21
Representative, glass sector	Sector and employee organisations	Dec-21
General manager, Research & Development organisation	Think tanks and research organisations	Jan-22
Representative of environment think tank	Think tanks and research organisations	Jan-22
Innovation lead, Liverpool City Region	Local authorities	Jan-22
Cities Network representative	Think tanks and research organisations	Jan-22
Member of think tank	Think tanks and research organisations	Jan-22
Representative, food sector	Sector and employee organisations	Feb-22
Representative, chemicals sector	Sector and employee organisations	Feb-22
Member of Energy System Catapult's markets policy and regulation team	Think tanks and research organisations	Mar-22
Representative, local authority network	Think tanks and research organisations	Jul-22
Representative, minerals sector	Sector and employee organisations	Jul-22
Senior policy officer, Non-Governmental Organisation	Think tanks and research organisations	Jul-22
Representative Energy Capital	Local authorities	Oct-22
Representative, metal processing industries	Sector and employee organisations	Oct-22
Black country consortium	Local authorities	Oct-22
Representative, North West business organisation	Local industrial decarbonisation initiative	Nov-22
Expert Advisor, Cheshire and Warrington Local Energy Partnership	Local industrial decarbonisation initiative	Nov-22

Case Study C: Expert interviewees (n = 14).

Role	Stakeholder type	Date
Research	Academic	Dec 2022
CEO	DNO	Dec 2022
Senior officer	DNO	Dec 2022
Analyst	Consultancy	Jan 2023
Senior Officer x2	Regulator	Feb 2023
System Forecasting Engineer x 2	DNO	Feb 2023
System Forecasting Engineer	DNO	March 2023
Senior Project Officer	Industry body	March 2023
System Forecasting Engineer	DNO	April 2023
System Forecasting Engineer	Energy System Operator	April 2023
System Forecasting Engineer	DNO	April 2023
System Forecasting Engineer	DNO	May 2023

Data availability

The data that has been used is confidential.

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