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Review

Beyond public acceptance: Towards systemic societal responsiveness of net zero infrastructures

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ABSTRACT

Whilst dominant science-policy framings focus on getting publics to accept widespread infrastructural changes deemed necessary for net zero, social science scholarship has argued for the need to move ‘beyond acceptance’. In this paper we advance on existing studies which tend to emphasise a largely sequential progression from acceptance to ‘beyond acceptance’ approaches. We suggest that this can be more accurately viewed as distinct co-existing and interacting perspectives on public responses to net zero infrastructures. We present a framework that identifies four perspectives on how publics relate to infrastructural change. This suggests that alongside perspectives focusing on *public acceptance* and *societal acceptability*, two alternative perspectives emphasise the need for *societal responsiveness* perspectives, one with reference to specific settings and one more systemically. Drawing on a review of academic literature and UK policy documents, we move beyond studies focusing on discrete technologies to analyse how these perspectives are evident across the energy system, with reference to three exemplifying case study areas: wind energy, greenhouse gas removal, and smart home technologies. Our analysis shows that public responses to net zero infrastructures are contingent on particular sociotechnical situations and are interrelated across wider systems. While *societal responsiveness* perspectives are emerging in contestation to the still dominant focus of gaining acceptance, we suggest that a more systemic perspective on societal responsiveness of net zero infrastructures is needed. We consider the research and policy-practice implications of this *systemic societal responsiveness* perspective in terms of public responses to, engagement with, and the governance of net zero transitions.

1. Introduction

The transition to net zero has emerged as an urgent matter of concern in the interest of limiting global average temperature rise to 1.5c [1]. This demands changes on an unprecedented scale, with energy generation, distribution, and end-use infrastructures and technologies playing a key part [2]. While the transition has predominantly been discussed with reference to technological, infrastructural and economic interventions, it is now widely recognised that society will also play a crucial part, but the specific nature of this role is disputed [3]. On the one hand, widespread urges to accelerate ‘the transition’ [4] often mean that ‘the public’ is viewed as a problem, barrier, or threat slowing down progress that needs to be overcome [4–6]. Dominant and highly durable science-policy framings – reflective of the pervasive ‘deficit model’ of members of the public as passive, knowledge deficient, irrational obstacles in the face of science and technological progress [7–9] – diagnose

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the net zero challenge as one of getting society to accept allegedly unavoidable policies, decisions and technologies. For example, the UK Government has suggested that:

> "Fast tracking carbon reduction requires gaining acceptance for and deploying at scale those technologies that are ready; accelerating the development of those that are not; and researching solutions to problems that do not yet have solutions" ([10], p.15).

On the other hand, whilst such acceptance-based approaches have become popular in attempting to reduce public resistance to new energy infrastructures [11], increasing evidence suggests that the drive to accelerate the transition with linear acceptance-based approaches can be counterproductive – for example where the development of low carbon infrastructures has been delayed, prevented, or failed to operate as effectively as intended, as exemplified, inter alia, by failed breakthroughs in the cases of onshore wind [12], greenhouse gas removal (GGR) [13], and in the roll-out of smart, low carbon home energy technologies [14]. Such failures have brought forward drives to more fully engage publics in low carbon technology and infrastructure development, yet they often reconstruct a framing of acceptance – in this case a broader, more process-oriented framing of societal acceptability – whereby public views are sought on a predominantly instrumental basis to justify largely pre-ordained decisions [15]. This lack of meaningful, upstream public engagement can inadvertently serve to undermine public trust in institutions and overall support for new net zero technologies [16].

In this paper we synthesise conceptual insights and case study evidence from the social sciences and relevant UK policy documents which show that narrow yet pervasive public acceptance framings are highly problematic and that net zero transitions depend on being more, not less, open and responsive to society. We introduce *societal responsiveness* as an alternative and more promising framing. Turning around the problem of gaining public acceptance to one of cultivating better societal responsiveness would not only lead to public support in instrumental terms, but would also ensure substantively better outcomes [17,18], and address underlying public concerns [19] – including those of equity, justice, and human needs [20] – while embracing the diverse roles, agency, and actions of publics who are understood to be innovative in their own right [21].

We seek to build and advance on existing 'beyond acceptance' work that has typically centred on studying discrete technological domains like renewables [22] or emerging technologies in the form of autonomous vehicles [23] and smart grid technologies [24]. Instead, our review takes a whole-system perspective on net zero infrastructures by dealing with diverse energy technologies at different scales and parts of the energy system. We suggest that, although societal responsiveness remains crucial when developing discrete net zero infrastructure developments in particular settings, a more systemic perspective is also needed to attend to the ways that public responses to different net zero infrastructures are themselves interrelated across wider sociotechnical systems. In doing this, we build on work that has developed relational and systemic perspectives on public engagement with sociotechnical change and low carbon transitions [25–28].

In the next section we set out a framework that identifies four distinct yet interrelated perspectives on how publics relate to infrastructural change. Here, we suggest that different approaches do not tend to progress over time in sequential research 'waves' defined by an increasingly sophisticated understanding of the relations between publics and infrastructural change and growing interest in public engagement as typically highlighted [11,22,29–31]. Instead, we argue that nascent 'beyond acceptance' perspectives emphasising societal responsiveness in specific situations and more systemically exist alongside still dominant linear public acceptance and societal acceptability conceptualisations. In Section 3 we analyse academic literature and UK policy documents to explore how these perspectives transcend research and policy-practice, with our analysis pointing to how different perspectives co-exist and interrelate across three exemplifying case areas of significance to net zero, namely: wind energy, GGR, and smart home technologies. Our analysis shows that despite emerging interest in how public responses to and engagements with net zero infrastructures are interrelated across wider systems, a more systemic approach to societal responsiveness is urgently needed to challenge dominant thinking that still falls short of adequately accounting for the social dimensions of the transition. In the discussion and conclusion we set out the research and policy-practice implications of this *systemic societal responsiveness* perspective in terms of public responses to, public engagement with, and the governance of, net zero transitions.

2. From public acceptance to societal responsiveness

Through synthesising relevant literature and conceptual insights, in this section we define four perspectives on how publics relate to infrastructural change. As presented in Table 1, this contrasts two traditional linear *public acceptance* and *societal acceptability*[1] conceptualisations and two alternative perspectives that go beyond acceptance to emphasise *societal responsiveness* in specific situations and in a more systemic sense. This builds on and applies existing frameworks that conceptualise distinct but co-existing perspectives on public engagement with sociotechnical change and relations between science and society (see [26,33,34]). As we outline below, the four perspectives on relations between publics and infrastructural change in Table 1 hold different assumptions and constructions about public responses, including the key intention, the sociotechnical object, how publics are viewed, the temporalities of public response, and governance implications. We posit, however, that these perspectives also co-exist and interrelate in practice. This is exemplified by contemporary policy documents [35–37] with multiple competing perspectives on the relations between publics and infrastructural change [18] and, thus, contradictory aims of securing public acceptance of predefined transition pathways whilst also striving for social justice and responsiveness.

In putting forth this framework, we build on existing 'beyond acceptance' reviews by scholars such as Batel [22], Wolsink [30] and Devine-Wright and Peacock [31] who chart progressive moves from narrow acceptance-based approaches to more critical studies which account for power dynamics and recognise the legitimacy of public perspectives and opposition. Our framework differs and goes further in three key ways. First, instead of highlighting a tendency of academic work to shift from public acceptance to 'beyond acceptance' understandings over time, our framework suggests these understandings can be more accurately viewed as distinct perspectives on public responses to infrastructural change that transcend research, policy and society and can co-exist, compete and interact any point in time. Second, rather than focus on specific technologies or sociotechnical objects in particular parts of the energy system (such as renewable energy technologies in isolation) our framework is reflective of multiple different technologies, infrastructures and associated social arrangements that will come forward across the system under net zero. Third, and relatedly, we add a further 'beyond acceptance' perspective that recognises the ways in which public responses to infrastructural change interrelate across wider systems.

[1] Given this paper's focus on the relations between publics and infrastructural change, we define *'societal acceptability'* specifically as an approach that intends to gain wider societal acceptance of net zero infrastructures through instrumental public engagement. This should not be confused with Wüstenhagen et al.'s [32] and Wolsink's [30] notion of *'social acceptance'* that includes wider society and also attends to the acceptance of renewables' innovation by markets and policymakers.

Table 1
Four perspectives on relations between publics and infrastructural change.

	Public acceptance	Societal acceptability	Situated societal responsiveness	Systemic societal responsiveness
Key intention	Getting individual members of the public to accept	Gaining wider societal acceptance through instrumental public engagement	Responsiveness to public concerns around discrete developments	Distributed responsiveness to societal concerns and actions across systems
Relevant sociotechnical object(s)	A discrete pre-given technological object (e.g. pre-established wind energy project)	A particular technological object (e.g. wind energy technologies)	A situated sociotechnical object (e.g. the sociotechnical dimensions of a wind energy development)	Multiple interacting sociotechnical objects (e.g. interactions between wind, other energy, and non-energy sociotechnical objects)
View of 'the public'	The public is irrelevant or assumed to have a deficit of understanding	Individual publics are invited to express their views	Recognises diverse, uninvited publics and communities of relevance	Publics are multiply engaged in diverse ecologies of participation in wider systems
Temporalities of public response	Limited time window within 'project time'	Early on and throughout technological development	Precedes and overflows any discrete development	Always ongoing and multiple
Governance implications	Technocratic governance (linear rollout of technology into society)	Consultative governance	Adaptive and responsible governance	Distributed and reflexive governance

2.1. Traditional perspectives: from public acceptance to societal acceptability

The *public acceptance perspective* which was predominant in the 1970s–1980s and still continues to inform at least some research and policy-practice, centers on those affected by discrete infrastructural developments. As exemplified by a consistent policymaker-practitioner focus on the urgent need to "understand consumer acceptability and behaviour" [38] and to "persuade people to accept and support big, intrusive changes" [39], the key intention of this perspective is to get individual members of the public to accept technologies and solutions proposed by science and policy. Such assertions are reflective of a 'deficit' model of public understanding [7], assuming that individuals act irrationally and lack knowledge of the benefits of green technologies, with early work informed by this perspective developing the concept of 'not-in-my-backyard' (NIMBY) to explain ill-informed local opposition to renewables [40].

Accordingly, and in line with rational choice theory understandings, opposition is interpreted as a problem that can be solved through communication and information provision or through financial incentives and compensation mechanism aimed at getting individuals to act more 'rationally' [23,41]. This is evidenced by: a) contemporary research interested in how stakeholders can best frame community benefits schemes as resonant compensatory mechanisms [42–44]; b) consistent interest in attending to the socio-psychological or other external factors that constrain 'rational' action or undermine the resonance of what's being communicated [45–48]; and c) the ongoing reliance of policymakers on education and monetary instruments as key tools for promoting behaviour change and technology acceptance (e.g. see [49]). This perspective is, in other words, associated with a technocratic mode of governing based on the linear roll-out of science and technology into society where public reactions are only relevant for a limited time window late on within the development timeframe of a specific local infrastructural project in isolation [50]. Such assumptions have had a lasting influence on how relations between publics and energy technologies are framed [11,22,51] and continue, especially within policy, to this day.

Critiques of linear models of public acceptance have brought about work that emphasises a *societal acceptability perspective* that places greater emphasis on understanding the wider societal dimensions of public responses and on broader social processes in engaging with affected and interested publics. Drawing on work in Science and Technology Studies (STS) and cognate disciplines including critical geographies (e.g. [52]), such work has challenged assumptions about the inherent benignity of green energy technologies – recognising a range of unintended consequences arising from large-scale processes of sociotechnical change, questioning the adequacy of credentialed expertise and project developers in accounting for and dealing with such unintended outcomes, and examining the broader institutional dynamics shaping transformations and responses to them [32,53]. Public responses to socio-technical change are therefore seen as being influenced by the ways people make sense of such processes, which depend on institutional contexts and shared cultural values [54], as well as on socio-psychological attachments to place reflecting shared experiences [55].

This second perspective is associated with a growing emphasis on the need, given uncertainties about unintended consequences of novel technologies, to: a) better account for personal, socio-psychological, cultural, contextual, and spatial factors shaping public responses through social science research eliciting public views and behaviours [55,56], with reference to a range of different theories on the determinants of technology acceptance or adoption, and b) an associated focus on including wider non-expert perspectives in the governance of innovation, which has led to the championing of deliberative processes and consultations [16,57], and community engagement [58]. To help anticipate socio-cultural processes and reflect on broader value-choices, the views and perspectives of non-experts therefore become seen as possessing validity alongside those of experts [7].

Nonetheless, while being open to public perspectives, values, and experiences, the key intention of this second perspective is to gain acceptance through largely instrumental public engagement. Individual publics are invited, most often by institutions and developers responsible for delivering a specific infrastructural project, to express their views on particular technological projects. This second perspective therefore holds a 'residual realist' view [59] of publics and participation as being discrete and pre-given, thus reconstructing a linear model whereby doing public engagement is assumed to lead to beneficial outcomes, including societal acceptance, gaining public trust, and so on [28]. Such understandings are prevalent in contemporary scholarship and policy-practice, with increasing interest in participatory forms of decision-making, as exemplified by the recent growth in national and local citizen's assemblies and other deliberative processes. Understanding public views through consultative forms of governance is seen as a way for those in power to"take citizens with [t]hem" [36], where greater public engagement is seen "as a means to improve the acceptability and success of resulting [net zero] legislation and policies" [60] and to "building local acceptance of new developments or infrastructure" [61].

2.2. Beyond 'mere acceptance': situated and systemic societal responsiveness

Whilst acceptance-based research (e.g. see [62–65]) and practice (e.g. see [38,66–68]) remain pervasive at an international level, for a number of years work in the critical social sciences, STS, and related disciplines has problematised the acceptance-based emphasis of the first two perspectives. The notion of getting 'the general public' to accept what has already been established by science and policy cannot, by definition, be reflective of and responsive to different public concerns, values, needs, and desired futures. Taking acceptance as 'the problem to be solved', closes down, obscures, and excludes alternative courses of action, and differences in responses from publics such as between active support, apathy, ambivalence, critical engagement with dominant models, and activism [11,69]. It significantly narrows down the possible roles of publics, to a reactive and instrumental repertoire that reduces possible forms of citizenship.

'Beyond acceptance' perspectives begin to turn around and reframe the problem to one of those in power recognising and responding to publics in all their diversities, with a nascent corpus of policy calling for a more socially inclusive and responsive transition governance, albeit of underlying commitments to ensuring speedy delivery of net zero [36,70,71]. More than this, it involves different actors – from institutions through to citizens themselves – recognising and being responsive to the diverse views, issues, concerns, and commitments of diverse publics [33,72]. This implies a broad shift in emphasis away from 'mere acceptance' to one which emphasises the need for just transition governance so as to acknowledge and include diverse public views and already existing engagements with energy infrastructures and climate change [73].

Critical deconstruction of many elements of the first and second perspectives articulates a third perspective that we call *situated societal responsiveness,* the key intention of which is to be responsive to public concerns around discrete sociotechnical developments. This represents an ideological shift from a normative focus on ensuring acceptance [69], accounting for how the deployment of low carbon technologies and associated decision-making processes can be apolitical, unjust and undemocratic. This more critical approach engages with aspects of recognitional, procedural and distributional justice [20]. It grapples directly with issues of energy injustice related, inter alia, to class, gender, race, coloniality, and power relations between publics and experts [29,74,75], while communicating the 'socially embedded' and co-created nature of societal acceptance in view of socio-historical and spatio-temporal factors [22]. Importantly, the objects of public response become seen as sociotechnical objects under this perspective, where specific energy technologies and infrastructures are viewed as sociotechnical configurations [76]. This recognises how public responses may already reflect ongoing engagements with societal issues that are relevant to but by no means reducible to technical aspects of infrastructure developments, including risk [77]. For example, responses relating to the purposes that lie behind the technology in question, who's in control, is it fair, to what extent do people have a say, and so on reflect engagements with social concerns that have wider significance but are translated into specific kinds of responses to energy infrastructure. In doing so, visions of more participatory or collaborative governance are often put forth as an alternative to technocratic approaches, with associated community-engaged research empowering publics to co-create transition pathways whilst also attending to the challenges associated with becoming more responsive to civil society on the ground (e.g. [75,78,79]).

An additional feature of this third perspective is a focus on how institutional framings exercise power by constraining engagement, often through the legal and administrative practices of planning governance [80,81]. For instance, such framings typically define rights of participation by relating them to spatial and temporal boundaries which identify "communities of the affected" upon whom rights are conferred. Batel [29] criticises these constructions, contrasting with them the concept of a "community of relevance" in relation to how "people can and are engaging with [energy technologies] in their daily lives, albeit outside arenas of institutional participation". Some researchers have pointed to how citizen engagement with energy infrastructures can be seen as an effect of spillovers from other issues [81]. A specific technology or project should not be seen as the primary cause of conflict, then, but instead as a condensation point around which concerns that relate to broader non-energy issues, often with social justice components coalesce. Citizens engaging with energy infrastructure may have previous engagements with similar issues that have shaped their experiences of political agency, and consolidated politicized identities.

Much of this perspective therefore mirrors work in STS highlighting how publics, forms, and objects of public engagement are not pre-given but are constructed through the performance of participation [33], where they can be closed-down by incumbent powers [15], but always overflow and extend beyond institution-led processes to encompass diverse forms of uninvited public engagement [80]. This recognises public engagements and forms of public relevance [82] as diverse and ongoing in ways that precede and overflow any discrete infrastructure development. The main governance implication under the third perspective is the move to being more deliberately responsive to public values and concerns, often in relation to particular projects or programs of science and technology, as shown by frameworks for responsible research and innovation for example (e.g. [83]). Some examples of this perspective can be found in contemporary policy discourse such as in calls for a more "inclusive decision-making process" that "understands and responds to people's concerns" and "puts people at the forefront of everything that we do" [36].

We suggest, however, that some of this work in STS and related fields points to the need to go even further in articulating 'beyond acceptance' perspectives, which goes beyond an understanding of societal responsiveness in relation to discrete sociotechnical developments in isolation. We therefore propose a fourth perspective that we call *systemic societal responsiveness*. This emphasises distributed responsiveness to societal concerns and actions across wider systems. In doing so, we build on recent work that has developed more relational and systemic perspectives on public engagement with sociotechnical change and low carbon transitions. This work has shown how public engagements are never limited to discrete forms of engagement with specific technologies or decisions, but rather are diverse and interrelate with each other across systems and ecologies of participation and innovation [26,27,33,84]. This opens up to the multiple, diverse, and plural ways through which publics are always already engaging with energy and climate change, including through material participation [82], mundane engagements with energy technologies [85], and so on. Such a perspective is nascent in policy discourse, although a few examples are emerging such as in the UK Department for Environment and Rural Affairs' (DEFRA) recent Review of Public Engagement which calls for "more equitable and pluralistic approaches to participation […] to address the diversity of publics"([86], p.12).

Furthermore, when publics engage with energy and net zero infrastructures, they do not only refer to specific technologies in particular instances. They also attend to other related net zero infrastructures and technologies as part of wider system transformations [25,87,88]. Relevant objects of public response are therefore multiple interacting sociotechnical objects, which might, for example include interactions between wind, other energy, and non-energy sociotechnical arrangements. The ways that publics receive or respond to a discrete new zero infrastructure will thus be shaped to some extent by their engagements with other technologies and practices, whether net zero-related or otherwise.

As a result, the fourth perspective we propose here differs in its move beyond being responsive to society in relation to discrete infrastructure developments, as is the case with the third perspective, to recognise more distributed forms of societal responsiveness in the wider systems associated with net zero transitions. Public engagements and responses cannot be solely defined by specific net zero infrastructure developments as they are always ongoing, multiple, and subject to overflows [89]. In other words, this perspective is responsive to multiple and diverse public engagements with many interrelated 'reliance systems' that shape public experiences of dependence and interdependence within a complex and inexorably interlinked socio-technical system. It decentres the notion of who is responding to – or being accepting of – who. In one sense, under this fourth perspective, sources of innovation and net zero infrastructure development are not limited solely to state and market actors and are distributed across civil society in the form of community energy groups, grassroots innovations, innovative social practices, and so on [90,91]. It follows from this that responsibilities for being responsive to society are also no longer limited to state, science, and market actors, but are also distributed across organisations and actors in civil society, including citizens themselves. Under this distributed and reflective governance, there is a need to build the reflexive capacities of actors, institutions, and distributed systems [33] in net zero transitions to attend to the uncertainties, indeterminacies, and politics of participation and the public outlined above.

3. Case studies of relations between publics and net zero infrastructures

We now present a critical review and analysis of existing academic literature and UK policy discourse exploring how these traditional and emerging perspectives on public responses are evident in three case areas of significance to net zero infrastructure, namely: wind energy, greenhouse gas removal (GGR), and smart home technologies. We focus primarily upon the UK in order to contain the empirical exercise, and because the UK is currently experiencing the beginnings of changes across multiple interlocking components of the net zero infrastructure challenge. Whilst these case study areas do not cover the whole spectrum of possible net zero technologies, they have been intentionally selected to reflect diversity in key dimensions of net zero infrastructures, including:

- The *temporalities* of technological solutions at different stages of development – i.e. mature in the case of onshore wind, through to emerging in the case of greenhouse gas removal,
- The different *spatial scales* at which they operate – i.e. the domestic scale in the case of smart home technologies, the local and regional scale with regards to onshore wind, and nationally significant infrastructure in the case of greenhouse gas removal, and
- The different *parts of the energy system* – i.e. energy production in the case of onshore wind, emissions management in the case of greenhouse gas removal, and energy consumption in the case of smart home technologies.

To obtain a comprehensive sample of social scientific literature and policy documents on the relations between publics and net zero infrastructures, we conducted a focused scoping review. This was informed by the extensive experience and expertise from across the authoring team who are part of one of the UK's leading and long-running energy research centres and drew on a publicly-accessible database of more than 500 cases of public engagement with energy and climate change in the UK since 2010 developed by some of the manuscript authors associated with the Public Engagement Observatory of the UK Energy Research Centre (UKERC) (e.g. see [92]). Whilst systematic in its own terms, a rapid review approach was selected to enable timely collation of evidence from across multiple and extensive bodies of scholarship and policy [93]. In doing so, and contrary to other systematic reviews on the relations between publics and net zero technologies (e.g. see [62,94]) where all available academic publications are considered for quantifiable bibliometric analysis, the focus was on identifying exemplifying empirical evidence and broader analytical themes emerging from both research and policy linked to the four perspectives introduced in Section 2.

To achieve this, we adopted a streamlined version of the 'PRISMA' principles for scoping reviews [95]. Alongside restricting evidence to predominantly UK-based contemporary research and policy, this involved adopting a core diversity inclusion criterion informed by the need to include different and diverse types of exemplifying evidence or seminal works (in terms of origin, empirical focus, intention, underlying perspective, and date published) to help provide a broader insight around the relations between publics and net zero infrastructures. Thus, whilst we acknowledge that our review does not capture *all* advances in scholarship and policy in relation to publics and net zero, it tries to comprehensively evidence how different perspectives are manifested and outline key trends. The critical review presented in the remainder of this paper draws on insights from a qualitative content analysis of the empirical corpus to deductively assess how the four perspectives on relations between publics and infrastructural change (see Table 1) are evident and play-out in research and policy in the three case areas. We now present the analysis of each case area in turn.

3.1. Relations between publics and wind energy infrastructures

Whilst wind energy is a technologically mature, widely deployed technology that is now capable of delivering electricity more cheaply than any other form of generation, wind energy deployment, especially onshore, has long been a controversial issue, as evidenced by multiple examples of public protest and opposition at the local and international level [96–98]. In light of decades of controversy over local wind turbines that contradicts seemingly favourable attitudes across society, social science research on the relations between publics and energy infrastructure developments has traditionally focused on wind energy, and empirical work in this area could even be linked back to the very emergence of studies on societal acceptance of technological change (e.g. [11,22,29]). In parallel, the governance of the relations between publics and wind energy has consistently been one of the key features of UK decarbonization policymaking (e.g. see [99,100]).

Specifically, the *public acceptance perspective* dominates contemporary UK wind energy policy, as evidenced by the strong focus on providing community compensation packages and information to overcome resistance to wind turbine installations. Indicatively, the recent 'Developing Local Partnerships for Onshore Wind' stakeholder consultation of the Department for Energy Security and Net Zero (DESNZ) emphasises a perceived "lack of awareness in communities around net zero and the role onshore wind can play" and "negative preconceptions, misconceptions, or misinformation around onshore wind development" as a key barrier, and highlights that "more effective communication could address this, particularly when trying to engage harder-to-reach groups" ([99], pp.9–10). Similarly, community benefit packages in the form of monetary benefit funds, in-kind benefits, and shared ownership options have long formed the backbone of onshore wind policy across the UK [100,101], with the new Labour government intending to work closely with industry partners to update such benefit protocols [102].

This approach is reflective of earlier scholarship on wind energy deployment to help overcome perceived public resistance to onshore wind farms [40]. Research aligning with this perspective has attempted to understand the barriers to public acceptance by often framing non-accepting publics as deficient in some form – in knowledge, trust or engagement [103,104]. As a result, 'the public' is seen to act as a potential barrier to the roll-out of wind energy. In spite of limited evidence that informed publics are more accepting of wind energy, many institutions have a firm belief that positive attitudes and, subsequently, greater acceptance of wind energy can be achieved through enhanced provision of information [45,55]. According to this logic, the 'public barrier' to wind energy deployment can be overcome if affected publics develop and share a common understanding of both the wider and locally-specific social and environmental goods associated with wind energy, thus bridging the apparent 'individual gap' between generally favourable attitudes to wind energy recorded in numerous social studies over the years, and less favourable responses to wind turbine installations recorded in-situ [104,105].

However, failure to meet these expectations can have knock-on effects leading to negative perceptions of public engagement in wind turbine planning processes [105]. Publics, despite being aware of the social and environmental good of wind turbines in light of continued efforts to counter a barrage of misinformation on wind energy, can still reject and protest against proposals on social justice grounds – as shown, for instance, by demonstrations of locals and environmental activist groups in Ceredigion, Wales [106]. There have also been cases where acceptance is simply taken for granted due to the preexisting siting of wind turbines, yet plans for expansion have sparked ongoing protest and direct action from affected communities (e.g. see for instance the Reay wind-farm protests in Caithness, Scotland [107]). It is, in other words, not sufficient to presume that publics who have knowledge or expertise regarding wind energy will be accepting of proposals – even with the social need for low-carbon transitions underscored, or with already existing infrastructure in place. Additionally, the often-cited Not-In-My-Back-Yard ('NIMBY') argument concerned with the seemingly paradoxical phenomenon of broad societal acceptability of wind energy coupled with specific resistance to locating turbines and wind farms in close spatial proximity to host communities has been rejected by much of the literature [40,108], and opposition shown to be informed by a range of factors beyond spatial proximity to wind projects [45,96,97,103,109].

A further body of research and practice aligned with the *societal acceptability perspective* seeks to invite public participation to better understand preferences and responses to specific wind energy projects. Through deliberative interventions with select mini-publics like Q methodology workshops [110,111], citizen's panels [112], interviews [108], and online consultations [113], amongst others, public views are elicited throughout the deployment of wind energy projects so as to support decision-making and improve a perceived democratic-deficit of decision-making around renewable energy infrastructure deployment [114]. These attempts, while appearing to consult with publics, still typically view 'the public' as a barrier to be overcome. For instance, whilst highlighting the need for a responsive approach to onshore wind development that sees "communities, developers, and local authorities work[ing] together effectively and for the mutual benefit of all involved" ([100], p.4), the flagship 'Good Practice Guidance' for community engagement developed by the former Department for Business, Energy & Industrial Strategy (BEIS) in 2021 revolves around the core underlying need to "build and maintain support for new projects" ([100], p.12). In other words, community engagement programmes and priorities are typically firmly rooted in top-down governance models and orchestrated by institutions for mainly instrumental reasons. They aim to increase public participation in the planning and development of wind energy projects during the early stages and throughout technological development and deployment to improve the social legitimacy and acceptability of outcomes [115].

Against this backdrop, there have been some, mainly scholarly, attempts to attend more explicitly to the broader sociotechnical dimensions of wind energy projects, with work aligning with the *situated societal responsiveness perspective* focusing on the conditions and contexts that shape public responses to specific wind energy projects, and accounting for diverse publics and engagements preceding and overflowing any specific or discrete wind energy development. Research aligning with this perspective explores the significance of place and value attachments [116] and conducts deeper qualitative research of diverse publics [51,69] by more closely studying the relations between local communities and actors involved in wind projects [117], the perceived impact of community benefits [118], and the justice and fairness implications associated with wind turbine siting [119]. Broadly, these works bring a wider range of public engagements around specific renewable energy technologies into view [74,120–122], and have demonstrated the role played by institutional and regulatory processes in constructing and constraining public voices and views, and excluding competing engagements and views from decision-making processes in an attempt to understand how wind energy infrastructures might become more socially responsive to public concerns and knowledgeable publics that precede any discrete wind energy projects [22,69].

While 'beyond acceptance' work on wind energy deployment still typically focuses on specific parts of the energy system and particular wind energy deployments, some emerging work on wind energy reflects our fourth perspective on *systemic societal responsiveness.* First, a nascent body of work directs attention to the pressing need for a more systemic understanding of societal relations with wind energy – accounting for the interdependencies of wind energy with other parts of the energy system. Specifically, there is growing interest in societal relations with technologies supporting higher wind energy penetration – including, amongst others, essential and oftentimes controversial grid and transmission line upgrades [123], smart home technologies helping address challenges to do with the intermittency of wind energy supply [124], and wind technology design that mitigates wind energy variability through electricity trade, battery storage, and demand side management [125].

Second, this perspective encourages us to attend to diverse, distributed, and innovative public engagements helping the transition to net-zero despite not being adequately recognised in dominant policy framings. Relevant work directs attention to the need to account for plural energy injustices more broadly as these have powerful implications on the ways in which wind energy technologies manifest themselves and have historically been envisioned across society [126]. In particular, with government support, funding and planning processes closing-down alternative transition pathways and futures, small-scale community wind energy technologies are still unsuitable to become an even more prevalent form of energy production due to a lack of infrastructure, technological expertise and grid capacity to deal with intermittent production or distribute excess wind energy [127]. Similarly, alongside challenging the assumption that civil society is necessarily a barrier to wind energy deployment (e.g. [128]), experience from wind-based community energy in the UK points to the lack of policy-maker responsiveness to the actual needs of the sector [129]. Indeed, the ephemeral policymaker support to community energy in the UK can be related back to strong instrumental rationales emerging in the 2000s, with policymakers almost exclusively focusing on how such groups can help tackle climate change (e.g. see [130,131]. Further, traditional and dominant policy visions for the energy sector are consistently found to give priority to large, centralized energy infrastructure and, subsequently, community energy projects are often found to focus their efforts on securing acceptance from the policy regime, becoming involved in intentional niche-development strategies that help secure their viability and future growth (e.g. [90,132,133]).

In short, moving beyond acceptance-based perspectives of wind energy enables us to better account for societal relations with wind and interrelated energy technologies. The social science literature and policy discourse summarised in this section encourages us to not only move beyond 'NIMBY' assumptions, to focus on the procedural and distributional justice and local identity implications of specific wind projects, but also to account for the uninvited, bottom-up forms of engagement with wind energy that are in turn shaped by broader institutional arrangements, interdependencies and power dynamics. This overview, though, also uncovers how significantly more effort should be directed towards shaping a novel agenda informed by the *systemic societal responsiveness perspective*. Amongst others, this should involve concerted effort to: a) bridge the gap between research that increasingly aligns with 'beyond acceptance' perspectives with practice and policy-making on the ground that is still dominated by acceptance assumptions, and b) attend to a much wider spectrum of public engagements with wind energy (e.g. protest, activism, prosumerism, digital and media engagement, etc.) and how such public engagements and responses are interrelated to other technologies across and beyond the energy system.

3.2. Relations between publics and greenhouse gas removal (GGR) technologies

GGR approaches and technologies figure prominently in net zero discussions, with the Committee on Climate Change discussing such technologies as "a necessity, not an option" ([134], p.23)(see also the UK's Ten Point Plan for a Green Industrial Revolution [135]). Even in a scenario of hugely ambitious efforts to reduce emissions, the UK would still rely on both engineered and land-based GGR to remove some 60MtCO2 every year by 2050 to compensate for hard to abate emissions [136]. In light of the critical importance of GGR, a variety of both mature and experimental approaches have been proposed, spanning industrial facilities for direct air capture, bioenergy with geological carbon storage, carbon capture and utilization, land-based approaches such as afforestation or enhanced mineral weathering, and blue-carbon ocean-based sequestration methods [137]. In all cases, GGR is far from a straightforward technological fix. Challenges include understanding systemic interactions across the energy system, the feasibility, risks, and ethics of achieving deployment at scale, and any impacts upon local environments and communities. This is likely to generate a series of contested frames through which debates about relations between publics and sociotechnical change will be played out [138].

Whilst GGR approaches are only currently emerging in the UK and have mainly been explored from a technological point of view, related work reveals a core concern around achieving public acceptance. Indicatively, such challenges figure prominently in the UK government's Net Zero Decarbonisation Report [49] as issues that need to be further considered and prioritized. This is suggestive of how GGR experts primarily focus on the instrumental need to explain the necessity for GGR and on the targeted provision of information appropriate for each audience as the primary ways forward for GGR technology rollout [139], with emerging empirical evidence from experimental GGR facilities (e.g. the Drax carbon capture and storage (CCS) project, North Yorkshire [140] and HyNet North West [141]) pointing towards the direction of significant efforts in developing comprehensive, multi-stage public communication protocols that go above-and-beyond statutory requirements with the ultimate aim to position the projects positively in the public consciousness.

Such discourses and tactics align with a long-established body of scholarship focusing on the relations between publics and geological CCS of power production emissions for at least two decades [138,142]. These studies tend to sit firmly within acceptance-based perspectives, in particular those stressing concepts of a locally-earned social license to operate [143]. Specifically, a significant amount of contemporary social science scholarship on GGR still draws heavily on the *societal acceptability perspective*. Given that many GGR approaches are still only notional and experimental, research and practice focus on getting publics to broadly accept specific technologies or approaches whose concrete form remains indeterminate. The relations between publics and GGR are predominantly studied through survey-based research that is often coupled with information provision or invitation to formal processes, with researchers aiming to inform first and then consult, as awareness amongst the public at large of GGR is currently believed to be very low [144–147]. In other words, whist GGR approaches are widely identified as emerging or 'upstream' technologies [57,148], their emergent quality is often only reflected in the public's assumed lack of specific knowledge of techniques.

Important exclusionary framing effects have also been recorded, pointing to a prominent instrumental rationale for public engagement. Researcher assumptions and commitment to securing delivery of GGR have been noted [149], demonstrating a firm commitment to getting publics to accept predefined pathways in place of being responsive to societal concerns and perspectives. Indicatively, some studies adopt an additional 'emergency' framing, in which GGR technologies are presented as a response to climate urgency and the failure of mitigation measures [150]. In this way, largely speculative technologies are presented as 'solutions' to an impending crisis, thereby 'closing down' debate around options. Relatedly, government-supported public dialogue processes, such as the CCUS Public Dialogue co-organised by the former Department for Business, Energy & Industrial Strategy (BEIS) and Sciencewise in 2020 appear firmly linked to the *societal acceptability perspective* in light of their core aims to: a) involve specialists and policymakers in discussion with the public to help raise understanding of and explore issues related to different types of solution, b) better understand public views and concerns, and c) actively explore conditions and pre-requisites for public acceptability [151]. Given these key intentions, it comes as no big surprise that formal process evaluations note a notable lack of flexibility in what was being discussed and how problems were framed, and the underrepresentation of expert stakeholders opposing CCUS in public dialogue processes [152]. More broadly, there is growing unease with current governance frameworks that make little provision for meaningful, upstream public engagement with GGR – relying, instead, on technocratic expertise and on legal specifications transforming deliberative and consultative processes into mere 'tick box' exercises with no guarantees of public responsiveness (e.g. see [153].

At the same time, public responses to GGR challenge such traditional perspectives on the relations between publics and sociotechnical change. First, in line with the *situated societal responsiveness perspective*, deliberative research and practice attends to the socio-culturally situated nature of GGR approaches, demonstrating how distributive, procedural, and recognitional justice concerns are central to public responses [154]. Such justice considerations include the distribution of costs and benefits across space and time, the relative power and influence of beneficiaries and other stakeholders, and the notable shortcomings of procedural justice measures in protecting public interests in decision-making about climate engineering [154], and are reflected in public discourse overflowing the typically narrow framings of deliberative processes such as the CCUS Public Dialogue [151].

Second, and most prominently, system spillover concerns are widely documented. Publics challenge a focus on discrete technological objects and point towards a *systemic societal responsiveness perspective* that sees GGR approaches as socio-culturally situated within a wider nexus of interrelating sociotechnical objects and system-wide societal concerns. For instance, some studies have examined how shared narratives associated with naturalness and the risks of tampering with natural systems are reflected in expressed public views [155–157]. The views of public respondents overflow even further, pushing back against discourses which present GGR as a necessary complement or backup to uncertain mitigation strategies. In particular, publics may be critical of GGR because it does not itself challenge reliance on fossil fuels, viewing it as needing to be part of a more comprehensive strategy to tackle carbon intensive lifestyles [138,142]. Critiquing 'emergency' and 'effectiveness' framings of such approaches, which tend to treat technologies as reified 'packages', scholars have instead argued that engagement should adopt 'unframing' approaches [149], using methods which construct invited mini-publics who are encouraged to bring a wide variety of lived experience related to comparable technologies and perspectives to bear.

In particular, mapping how different issues interact with each other systemically has been a central concern of approaches which use more deliberative approaches with purposively sampled mini-public, with the literature emerging around the use of deliberative participatory methods being notably broader in its framings and much less constrained in its elicitation of participant reasonings when compared against deliberative processes on other technologies [158,159]. For example, deliberative focus groups have explored the ways in which public concerns combine with experiences of other energy technologies, with perceptions of GGR as an uncanny disruption to natural systems shifting when contextualised to include either concerns relating to the intermittency of renewables or when, or evidence on industrial and bioenergy applications supporting wider natural and economic interdependencies [160]. Further, upstream participatory appraisals of options for responding to climate change have employed a Deliberative Mapping approach to open-up consideration of GGR alongside a diverse range of other options for responding to climate change whilst involving citizens, experts, and stakeholders in a symmetrical, interactive, transparent, and systematic appraisal process [88,159]. These considerations are particularly important given the temporal complexities of GGR approaches which are best compared not to discrete installations, but to entire new systems of interlinked practices, technologies, and institutions whose life-cycle runs into an open, indeterminate future [161].

Multiple different interrelating concerns and sociotechnical systems have been uncovered by research adopting a *systemic societal responsiveness perspective*. Publics tend to respond to GGR in relation to: a) previous experiences of polluting and hazardous technologies [143,162]; b) trepidations around GGR as a form of 'non-transition' raising key temporal dilemmas [138] and concerns around so-called climate change mitigation deterrence [163]; and c) the need for GGR approaches to be embedded in complex social systems in order to work as intended, including through attending to concerns about (inter)national governance [162]. All these broader concerns are manifested in public ambivalence and highly conditional support vis-à-vis GGR approaches [164]. This reflects the inherent complexity of such approaches – both in terms of the wider societal conditions that would need to be in place to make them feasible, and the potential complex and uncertain interaction with social and natural systems that might give rise to unintended consequences [165].

In short, evidence presented in this section points to how treating GGR approaches as easily isolatable socio-technical objects in line with traditional acceptance-based perspectives is problematic – even more so when the potential implications for mass deployment governance are considered (104,116,117,118). Accordingly, and against a backdrop of a bulk of policy and practice aligning with acceptance-based understandings on the relations between publics and infrastructural change, some scholarship on responsible innovation and geoengineering views GGR approaches as a major political program given the need for (trans)national institutional change to govern them (ibid.). Such emerging scholarship on publics and GGR therefore reflects more firmly characteristics given in the third and fourth perspectives introduced in this paper. Recognition of the socially embedded nature of GGR approaches and their relations to other elements of socio-technical systems leads beyond restrictive framings of technology objects, issues and publics, though the highly upstream nature of GGR does mean that engagement with publics tends to be formal and invited. At the same time, the formalized nature of key engagement studies has been associated with increased institutional reflexivity in response to study findings, with some early approaches to GGR experimentation and publics seemingly 'represent[ing] a high-water mark in terms of the influence of structured mini-publics on policy-making, at least in relation to the formulation of a governmental research funding agenda in the UK' [149].

However, in spite of *systemic societal responsiveness* sensitivities informing some emerging research and practice on GGR, responsiveness, reflexivity, and whole-systems thinking should not be taken for granted. First, given the growing prevalence of deliberative mini-publics documented above, there still remains a pressing need to better recognise diverse uninvited publics and communities of relevance and account for publics as being multiply engaged in diverse ecologies of participation in wider systems, as suggested by the *societal responsiveness* and *systemic societal responsiveness perspectives* respectively. Second, in line with growing calls for systems- in place of siloed-thinking in how net zero is being governed, significantly more effort is needed to ensure GGR governance becomes reflexive and distributed.

3.3. Relations between publics and smart home energy technologies

With households recognised as critical components of the net zero transition (e.g. see HM Government's Net Zero Strategy [166]), we have witnessed significant moves towards a whole suite of changes designed to create more active and responsive domestic energy consumers in a low carbon, smart grid. These include the rollout of smart meters and energy feedback technologies, different forms of tariff innovation generating demand responsiveness, the diffusion of energy management systems and smart home technologies to increase efficiency and automate household responses, growth in domestic micro-generation technologies, and the subsequent emergence of peer-to-peer energy trading. But whilst research and practice on home energy decarbonisation is broadly recognised as a 'technology push' field [167], there has also been consistent focus on the social dimensions of the shift promoted. This is, most notably, evidenced through a persistent policymaker concern with ensuring that individual consumers actually "accept and support these big, intrusive changes" [39], with consumer behaviour and acceptance of innovative domestic energy technologies seen as a critical area of research and intervention (e.g. [10,39,166]).

Indeed, in line with the *public acceptance perspective,* public acceptance and domestication of innovative domestic energy technologies has received a great deal of research and policy attention (e.g. [38]), with a persistent rhetoric around a policy approach that "must be customer oriented, promote behaviour change and public education on the tangible and financial benefits of decarbonisation" [49], and an associated view of energy publics as "no-nonsense pragmatists who can make decisions based on the information" provided to them in the interest of saving money and energy [168]. This reflects assumptions linked to rational choice theory and to the core, dominant assumption that providing information on the benefits of smart home technologies and making energy visible through smart feedback helps transform passive end-users into micro-resource managers [169,170]. It has been attempted through multiple initiatives addressing a perceived information-deficit – providing more and better information on energy use through smart meters, expected to raise consumer knowledge and, subsequently, encourage consumers to reduce, curtail, or shift demand (e.g. [171–173]).

However, approaching the issue from a *public acceptance perspective* has largely failed to deliver on the promises of home energy decarbonisation. Most prominently, social science research points to "a mismatch between planned (often aspirational) objectives and the realities of implementation" of smart energy systems ([174], p.13). Smart energy technologies have met widespread resistance, with the significant delays in the UK smart meter rollout signaling how technocratic governance can often result in higher costs, fewer social benefits, and lower than expected energy savings (e.g. see [175]). This has brought about two notable shifts. On the one hand, we have witnessed efforts to improve practice on the ground through renewed commitment to approaches linked to the *public acceptance perspective*. This is exemplified by: a) efforts to increase the efficacy of smart metering (e.g. [176,177]), including, inter alia, by providing smart energy feedback to broader community groups (e.g. [178,179]), combining smart feedback with tailored messaging that taps on social norms [180], and through different forms of tariff innovation that encourage demand responsiveness [180]; and b) by the flagship '4As: Awareness, Acceptance, Access, and Adoption' framework introduced in 2024 by the UK government-initiated organisations 'Smart Energy GB' and 'Behavioural Insights Team' that outlines a comprehensive marketing and communications route for ensuring acceptance of smart home technologies [181].

On the other hand, and in line with the *societal acceptability perspective*, we have witnessed an apparent shift towards invited, instrumental public engagement and opinion elicitation. First, there have been various moves to understand the issues that diverse publics face in adopting such technologies so as to accelerate their uptake. Indicatively, the Smart Metering Early Learning Project of the former Department of Energy and Climate Change (DECC) [182] administered a series of surveys and focus groups to help identify consumer barriers to the success and rollout of smart meters. Such work is linked to technology adoption models informed by the Theory of Planned Behaviour and work on the Diffusion of Innovations (e.g. see [183–185]), and includes attending to social barriers to adoption such as: a) trust issues and resistance; b) users' limited perception of their usefulness; c) a series of financial concerns; and d) public concerns related to privacy and cybersecurity (e.g. [186–188]). In conjunction, we have witnessed moves towards more consultative approaches with diverse mini-publics – including through deliberative workshops and citizen juries and panels (e.g. [189,190]). Whilst helping to develop a better understanding of public concerns and preferences around home energy decarbonisation, these deliberative processes have predominantly adopted an instrumental rationale that seeks to address pre-identified policy gaps or boost the societal acceptability of existing transition trajectories, rather than exploring alternative pathways. This aligns with the approach of 'Smart Energy GB' that might prioritise information-provision and awareness raising, but also sees a role for "two-way public engagement to listen to the public, understand their concerns, and in turn create better, more widely supported policy and delivery' [181].

In parallel, work focusing on the use of smart home technologies has been opening up to societal concerns relating to how these domestic technologies become situated in specific everyday lives and households and the wider social effects they bring about, with the UK-government supported Living Labs of the Energy Systems Catapult testifying to growing interest in public experiences and concerns. Whilst such living labs often serve an instrumental agenda of refining largely predefined technological pathways [191], research aligning with the *situated societal responsiveness perspective* draws on social practice theory understandings to push forward a more socially responsive and responsible stance associated with post-technological conceptions of 'socially smart grids' [192]. Explorations of domestic life have been considering domestic energy technologies as socio-culturally situated objects, and have re-envisioned smart, low carbon homes as complex meaning- and emotion-laden places where different household members with different roles and relationships with technology must interact and negotiate their wants and needs, all of which need to be fully explored and accounted for when developing smart technologies [193–195]. Further, smart energy technologies have been explored in relation to the immense complexity of coping with the routines of everyday life [196,197], with research attending to issues around everyday household social dynamics, and domestic roles, relations, and responsibilities shaping adoption and use of smart technologies [14,198–202]. Accordingly, there is an oft-cited mismatch between the objectives and realities of smart home decarbonisation as evidenced, for instance, through unintended energy intensification trends, and the inability of technological solutions to challenge energy-intensive lifestyles [203].

As part of research aligning with the *situated societal responsiveness perspective*, attention is also increasingly placed on how different special interest groups interact with domestic energy technologies. First, there is growing interest in gendered practices in smart homes [204–206]. Against a backdrop of energy industry imaginaries that prioritise technical interests and masculine pursuits [207,208], there is growing recognition of how such technologies are gendered by design or ergonomics, often prioritising masculine fantasies of technology as an ideal housewife that can take care of domestic responsibilities [207,209,210] whilst effectively realising energy demand-response ambitions [205,211]. Second, there is growing focus on how vulnerable individuals are affected by smart technologies, with research [212,213] challenging industry claims that these technologies might help deliver home energy decarbonisation whilst simultaneously addressing fuel poverty. Third, work within this perspective attends to broader moral and ethical concerns relating to energy justice and democracy. This work has emphasised public concerns around inclusivity in decision-making [214–216], has questioned whether smart grids are suitable vehicles for addressing wider justice issues [217], and has uncovered growing interest in more decentralised and democratic ownership, governance, and decision-making [192].

But research on low carbon homes also points to the need for a *systemic societal responsiveness perspective*. A nascent body of work draws attention to multiple different interacting sociotechnical objects and arrangements to show that societal engagement with domestic energy technologies is fundamentally shaped by issues and objects that extend and overflow beyond specific technologies and connect with wider sociotechnical systems and developments. Amongst others, Bolton et al. [218] point to the futility of targeting people as isolated individuals when their energy-related decisions are inexorably shaped by complex webs of pre-existing social relations including family, friends, and communities. Broader social identities and energy biographies are also critical [219]. For example, people who are less familiar with IT-based solutions tend to respond less well to living with smart home technologies [220]. In a similar vein, wider socio-cultural concerns around surveillance and growing unease with the practices of major corporations lead to concerns around domestic energy technologies expanding new forms of control and surveillance into homes [200,221]. Further, changes in wider systems of practice unrelated to energy shape engagement with emerging domestic energy technologies [222,223], as exemplified by broader trends in ICT and the growing digitalization of daily life [224], or Strengers et al.'s [225] observations on how the evolution of pet-care practices is contributing to the adoption of smart technologies. Finally, households are increasingly positioned not just as energy end-users, but also as potentially key system actors, with emerging trends in prosumerism, energy entrepreneurialism, and peer-to-peer trading introducing new forms of household conduct and modes of 'governing the self' [226] that involve active sociotechnical interconnections across the energy system [170,227].

In short, moving 'beyond acceptance' in domestic settings suggests abandoning the still dominant policy idea that people will just accept smart and low carbon energy technologies if given more information, better incentives, or if engaged for predominantly instrumental reasons. Instead, emerging research highlights the significance of different social practices, responsibilities, relations, and household dynamics and how these are shaped and in turn shape domestic energy technologies, whilst simultaneously linking individual householders into broader governance arrangements and technological systems. Whether or not households and wider society actively 'accept' or adopt emerging domestic energy technologies is fundamentally contingent on a much wider array of issues and concerns that extend substantially beyond isolated technologies themselves. Whilst considerable progress has been made in accounting for such dynamics, notable gaps in research and policy-practice remain. Not only does the bulk of work – and especially policy discourse – in this field focus on discrete and isolated moments of acceptance of specific domestic technologies, but even work aligning with the *systemic societal responsiveness perspective* would need to better account for the broader trajectory and evolution of diverse and interconnected sociotechnical systems. For instance, rather than focusing specifically on smart technologies and their uptake, future research and practice should account for everyday (domestic) life in broader terms and for diverse visions of future life and how they might, in turn, connect to smart technologies in turn relate to the design, implementation and embedding in society of. In doing so, instead of relying on in-depth insights from a limited number of experimental living labs in isolation, a broader range of methodological approaches would be needed, such as multi-sited ethnography and citizen social science biographical and temporal designs and analysis across multiple different contexts within and beyond the house and across multiple different communities.

4. Discussion and conclusions: towards societal responsiveness of net zero infrastructures

In this paper we have set out a framework based on four perspectives on the relations between publics and infrastructural change and have explored how these play-out across net zero infrastructures in a more systemic sense. Through our review of scholarship and UK-based policy documents, we have shown how *societal responsiveness perspectives* are emerging in academic and, to a lesser extent, policy worlds across all three exemplifying case areas. These 'beyond acceptance' perspectives are found to offer much richer insights into public responses to infrastructural change – recognising diverse publics and communities of relevance, accounting for public concerns and the justice implications of net zero, and their interrelations in wider systems. This suggests that narrow *public acceptance* or *societal acceptability* framings for net zero infrastructure development are problematic, and that effective net zero transitions depend on being more, not less, responsive to society.

Insights from our review emphasise different aspects of this in relation to our three case study areas. With regards to wind energy, we are encouraged to not only attend to the procedural and distributional justice and local identity implications of specific wind projects, but also to account for the uninvited, bottom-up forms of engagement (e.g. community energy) that are shaped by broader institutional arrangements, interdependencies and power dynamics. From a *systemic societal responsiveness perspective*, GGR is reframed as a major political program involving change across multiple levels, including in challenging current governance approaches and carbon-intensive lifestyles and environmental practices. Finally, *systemic societal responsiveness* challenges efforts to secure smart energy acceptance through the provision of information and incentives, inviting us instead to systematically focus on different social practices, responsibilities, relations, and household dynamics whilst simultaneously linking individual householders within broader governance and technological systems.

Yet, in spite of *societal responsiveness* concerns being increasingly reflected in contemporary discourse around publics and net zero, our review points to the pitfalls of viewing this as a new 'wave' of thinking and doing, as previously proposed (e.g. see [11,22,24,29]). Instead of outlining a largely sequential progress of thinking and doing, our framework and case study evidence suggest this can be more accurately viewed as distinct perspectives on public responses to infrastructural change that co-exist, compete and interact at any point in time, transcending research, policy and wider society. Specifically, against the backdrop of scholarship challenging acceptance perspectives, policymaking and research on net zero technologies testify to the continued endurance of acceptance-based conceptualisations – further validating previous research outlining the UK as a technocratic state that consistently excludes or views civil society as a barrier in transition and innovation processes, in spite of a diversity of actually-existing productive public engagements with net zero (e.g. see [84,92]). This persistence of acceptance-based thinking and doing undermines the transformative potential of research and policy moving 'beyond acceptance' by prioritising and legitimising top-down models of governance and scientific authority. Some nascent, more responsive policy discourses and academic work is at odds with the bulk of policymaking on the ground, and suggesting that more participatory – and seemingly responsive – governance approaches are mainly being pursued by those with decision-making power for instrumental reasons. Whilst our review focused on the UK, similar trends are also apparent at an international level, with a continued proliferation of acceptance-based research (e.g. see [62–65]) and policy-making (e.g. see [38,66–68]). In this vein, whilst *societal responsiveness perspectives* invite us to recognise multiple and diverse publics, there is growing unease with how publics are still primarily seen as passive actors, knowledge deficient, not engaged, or as obstacles that need to be overcome so that specific technical solutions can be implemented with minimal resistance.

Furthermore, our analysis reveals that work that moves 'beyond acceptance' still falls short of adopting a truly systemic and relational perspective. In spite of some advances, issues that should figure more prominently in an analysis informed by the *systemic societal responsiveness perspective* are still underexplored. Our case study areas point to how net zero infrastructures and diverse public responses to them are interrelated across wider systems, but these interactions tend to be overlooked by much existing work. Subsequently, our findings suggest a transformative shift is needed in how relations between publics and net zero infrastructures are understood, studied, and governed. In moving 'beyond acceptance', *situated societal responsiveness* is important but a more *systemic societal responsiveness perspective* is also needed. We now consider the research and policy-practice implications of this perspective in terms of: (i) understanding public responses as interrelated, (ii) taking a systemic approach to public engagement, and (iii) cultivating responsive governance across systems in net zero infrastructure transitions.

4.1. Understanding public responses as interrelated across systems

First, our analysis emphasises the need to understand public responses to net zero infrastructures as interrelated across wider systems. Despite some research from across all three case areas pointing to systemic interrelations, our review also documents the persistence of work aiming to understand public responses in relation to discrete technologies and infrastructures in isolation (e.g. the decades of research on public perceptions of renewables, CCS, and smart technologies summarised in our review in Section 3). This is in sharp contrast to whole-system technical energy modelling that currently figures prominently in thinking around net zero, with the UK TIMES [228] and the Energy Systems Catapult's modelling capabilities [229] forming the backbone of UK net zero policies, and attending to the complex interactions of power, gas, heat, and transport and the different ways in which energy is supplied, managed and consumed at different levels. Accordingly, there needs to be a more concerted effort for research on the relations between publics and net zero infrastructure to develop such whole-systems thinking by attending to how public responses are interrelated across multiple different technologies, infrastructures, and associated social arrangements that come forward under net zero. Although we focus on three specific types of net zero infrastructure, many other novel aspects of energy infrastructure for system change are also likely to evoke similar responses, concerns, and interconnections. Accordingly, this points to the necessity of whole-systems social science scholarship that systematically attends to how public responses and engagements linked to specific technologies and infrastructural projects are inexorably interrelated to a vast spectrum of multiple different infrastructures across the energy system. Moreover, rather than looking at perceptions on discrete infrastructures or focusing on the energy system, we advocate attending to how responses to green and smart energy technologies are shaped by broader fossil fuel-based lifestyles and associated social imaginaries, and by the relations between publics and decision-making institutions. Further, with net zero transitions requiring new systems of production and consumption that re-shape multiple different routine everyday practices, there is a need to better attend to the lived experiences of the transition and, thus, to the complexity of relevant socio-technical systems and to potential frictions, conflict, and competing demands as people are being asked to become more sustainable across different domains of their lives as consumers and (local) citizens.

Understanding public responses to net zero infrastructures as interrelated has policy implications too. Instead of focusing on specific infrastructures and technologies in isolation, all of our examples point to how policymaking should deal explicitly and systematically with the interdependencies of net zero infrastructures and the interrelatedness of public responses to them. For instance, whilst open communication remains important for informed public engagement in the face of emerging populist misinformation on net zero, such campaigns need to better reflect the systemic interdependencies of the net zero transition – contextualising specific decisions or infrastructural developments within a broader landscape of net zero technologies and societal arrangements to reinforce the need for publics and policymakers alike to engage with net zero from a whole-systems perspective.

4.2. Taking a systemic approach to public engagement with net zero

Second, a systemic societal responsiveness perspective points to the need to take a systemic approach to public engagement with net zero infrastructures [92]. This moves beyond the current focus on isolated, often one-off engagement events such as citizen assemblies, consultations, and other deliberative processes focusing on specific projects, technologies, or isolated parts of the energy system. One necessary move is to engage publics in whole-systems questions about net zero. Recent research (e.g. [25,87]) has already built on developments in national-scale public participation processes to elicit public attitudes and values on alternatives for energy system change, taking an important step in moving to a whole-systems perspective and identifying public values that should guide future energy system transitions. Moreover, the approach of (Distributed) Deliberative Mapping [27,88] provides an alternative to typical single-issue and narrowly-framed deliberative processes conducted over the past years, opening-up the framing of the problem, possible solutions, the actors involved, and broadening out to include already-existing citizen groups alongside experts and a convened deliberative mini-public.

Taking a systemic approach also means going beyond invited, institution-led engagements to map diverse forms of already existing public engagements with net zero across wider systems [27]. Approaches to mapping multiple and diverse, invited or uninvited, forms of public participation and engagement across different energy and climate-related issues – including comparative case analysis mapping, citizen social science, and digital methods [27,84,92,230] – should figure more prominently in future research and practice as they can inform more societally responsive practice by offering more plural and comprehensive insights into publics, their values, actions, and alternative pathways. Public engagement observatories monitoring publics and their diverse and interrelating engagements across wider systems, debates, and ecologies of participation on an ongoing basis are one example of new entities and organisational forms that are required to advance systemic approaches to public engagement through mapping and experimenting with diverse interrelated forms of public engagement across systems, and linking them to policy and practice in new ways [230].

4.3. Cultivating societal responsiveness across systems

Finally, our analysis directs attention to the pressing need to reframe the problem of public acceptance to one of cultivating societal responsiveness of net zero infrastructures and institutions across wider systems. Systems of governance need to move beyond the current emphasis on gaining public acceptance to take practical steps to become more responsive to – or accepting of – public concerns, values, and actions on a whole-systems level. In the context of imperatives to accelerate the net zero transition, this should inform the development of more ongoing, distributed, and responsive systems of governing, where public values and actions are not seen as fixed but in flux and continually emerging. This would involve developing new processes and ways of cultivating institutional responsiveness to diverse publics, such as protocols to regularly engage with and respond to public engagement mappings, and using mappings of existing engagements [27,92] as a standard starting point before new invited public engagement exercises are initiated. Crucially, this need for institutional responsiveness not only applies to national governments but is also distributed and relevant to multiple levels and actors including local government, businesses, community groups, activist organisations and more. Another likely feature of a *systemic societal responsiveness perspective* around net zero infrastructures would be to embed the values and criteria evident from systemic public engagements and mappings into net zero governance and decision-making approaches, with an understanding that such values evolve and would need periodic refreshing [92].

There are many challenges to cultivating systemic societal responsiveness around net zero infrastructures in practice, not least incumbent neoliberal models of governance and the vested interests of power which do so much to maintain the status quo. Such approaches are likely to be perceived by policy and decision-makers as difficult and time-consuming, though it is clear that current approaches are also difficult and are not yielding outcomes which are socially just or which represent accelerated progress towards net zero goals. Another concern often levelled at these kinds of approaches is that they risk slipping into relativism, and in this case may give oxygen to malevolent and powerful interests, such as those stoking anti-net zero sentiments and actions. We would argue these concerns are misplaced, as it is important for governance actors to be aware of all these actions and views in order to respond effectively and to openly acknowledge the contours of debate. To address this, there are emerging tools and approaches such as frameworks for responsive governance [231], Responsible Research and Innovation [83], community-based participatory research (e.g. [75,78,79], and experiments orchestrated by public engagement observatories where systemic mappings of public engagement are enabling net zero decisions, innovations and participation processes to be more responsive to society (e.g. see [92,232]). The challenge of maerialising such approaches more fully is precisely the challenge we face in order to realise our net zero ambitions.

CRediT authorship contribution statement

Phedeas Stephanides: Project administration, Conceptualization, Writing – review & editing, Writing – original draft. **Nicholas Pidgeon:** Writing – review & editing. **Christopher Groves:** Writing – review & editing, Writing – original draft. **Helen Pallett:** Writing – review & editing, Writing – original draft. **Tom Hargreaves:** Writing – review & editing, Writing – original draft. **Elliot Honeybun-Arnolda:** Writing – review & editing, Writing – original draft. **Jason Chilvers:** Writing – review & editing, Writing – original draft. **Robert Gross:** Writing – review & editing. **Karen Henwood:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Data availability

No data was used for the research described in the article.

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