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## Delivering net zero in the UK: twelve conditions for success

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## LETTER

## Delivering net zero in the UK: twelve conditions for success

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E-mail: [rachel.carrwhitworth@gmail.com](mailto:rachel.carrwhitworth@gmail.com)**Keywords:** net zero, energy system change, stakeholder deliberation, climate policySupplementary material for this article is available [online](#)**Abstract**

Reducing greenhouse gas emissions to net zero (NZ) as rapidly as possible is imperative to limiting climate change, and this requires an unprecedented transformation of socio-technical-political systems which govern the energy system. To guide this transition, evidence from a broad range of disciplines is needed, yet rarely are experts able to speak with a coordinated voice on the conditions needed to transform the whole system. Here we draw on novel data from a series of deliberative workshops utilising consensus building techniques with 83 experts and stakeholders from the public, private and third sector, to understand the conditions needed to deliver NZ in the UK. About 12 core conditions are presented: (1) act now to deploy 'low regret' solutions on a large scale; (2) to learn from successes and failures, monitor, evaluate and communicate outcomes; (3) clarify governance structures, expectations and responsibilities; (4) upskill and capacity build in the workforce and government; (5) better account for the importance of place and spatial dimensions of the NZ transition; (6) actively engage communities in the changes taking place; (7) realise a just transition; (8) challenge the role of power and vested interests in downplaying and delaying NZ; (9) take an interdisciplinary and whole systems approach; (10) review the research and innovation funding landscape; (11) incentivise collaboration and reward impact; (12) explore competing narratives and transition pathways. Taken together, these conditions can guide decision making and future research agendas in climate change mitigation.

**1. Introduction**

Global analysis by the Intergovernmental Panel on Climate Change establishes the need to deliver deep cuts to greenhouse gas emissions over the next decades and reach net zero (NZ) emissions 'in the early 2050s' to avoid the worst impacts of climate change [1]. The UK government has committed to reduce national emissions by 78% by 2035 compared to 1990 levels, and reach NZ by 2050 [2]. Rapidly reducing cumulative emissions is imperative, meaning the actions taken in the next decade will define whether long term climate goals can be met. Achieving this requires an urgent and unprecedented transformation of current energy systems, land use, industrial systems, infrastructure and the social and cultural

practices which interact with these systems [3–7]. However, analysis from the UK's independent statutory body on climate change shows that the UK is currently off track to achieve these changes in a range of areas, making it increasingly challenging to meet its climate commitments [8].

The scale of this socio-technical challenge means it is essential that insights from multiple disciplines are used to guide this transition. However, the challenge is often framed as a technological transition and not a complex system involving social, economic and political change [9]. For many years, a large amount of research has been funded to develop new low carbon technologies, assess the costs, barriers, and enablers of deployment, and explore the policies and incentives which are needed to deliver

decarbonisation [10–13]. Research has also taken a whole systems approach to assess the potential impacts of mitigation measures, assess the different ways they could be deployed through the development of NZ scenarios, and explore the broader social and economic implications of an NZ transition [14–16]. Despite this, a significant gap exists between the mitigation options identified by research and the reality of what has been achieved in practice. Some research has explored the conditions needed to close this gap and transform specific sectors [17, 18], however, despite frequent calls to take a whole systems approach to NZ, there is a lack of work which brings this knowledge together for the NZ transition as a whole.

In this paper, we utilise deliberative consensus building methods to elicit expert and stakeholder views on the conditions needed to deliver a rapid transition to NZ in the UK. Expert deliberation is a widely used approach in futures studies for envisioning solutions in the face of complexity, considering different possibilities and evaluating drivers of change and their interlinkages [19]. Deliberative methods are a valuable tool for exploring stakeholder perspectives, areas of consensus and disagreement around complex problems, and are increasingly recognised as a useful tool to inform climate policy [20]. Such approaches have been used for some time within the field of Science and Technology Studies (STSs) [21] and in risk research [22]. In STS the emphasis is placed upon exploring the competing values and imaginaries which can drive ‘upstream’ scientific developments in different directions. In risk research they have been used to understand the discourses and debates involved in achieving consensus in highly conflicted risk situations [23]. In recent years there has been a proliferation in the use of deliberative public processes to inform decarbonisation policy, through the national citizen’s assemblies in the UK, Ireland and France and numerous regional citizen’s juries [24, 25]. Yet to our knowledge, there have been no attempts to use these techniques to bring together expert and stakeholder knowledge from across the whole climate and energy field, to explore the extent of cross-sector consensus on the conditions needed to deliver NZ.

We carried out a series of workshops with participants with expertise across the climate and energy field, to explore the extent of consensus around a shared narrative for how NZ can be achieved. We also explored with participants the potential role of research in delivering this narrative. Following a brief overview of our methods, this paper distils 12 ‘conditions’ for delivering NZ which synthesise key messages for multiple stakeholder groups including the public, private and third sector, and the research community.

## 2. Methods

Data was collected through a series of 8 one day deliberative workshops with researchers and stakeholders ( $N = 83$ ), carried out between February and November 2021. Workshops were designed in a process of three ‘rounds’, each with slightly different aims, designed to build on the outputs of the previous round. In the first round, two workshops were carried out with experts from the research community ( $n = 23$ ,  $n = 19$ ). The second round involved four workshops with participants from four sectors, respectively: the public sector ( $n = 10$ ), private sector ( $n = 12$ ), third sector ( $n = 12$ ) and the funding and investment community ( $n = 7$ ). The final round brought back the original participants from the research community for two more workshops ( $n = 12$ ,  $n = 16$ ).

### 2.1. Stakeholder recruitment

Participants were selected through a detailed stakeholder mapping process, aiming as far as possible to represent the field of climate change mitigation as a whole. Purposive sampling was used to identify participants, with snowball sampling used in some instances where participants were unavailable. An ‘expert matrix’ was generated, following methods for expert stakeholder identification in Neef *et al* [26], to generate a ‘long-list’ of primary stakeholders. For the research community, participants were selected to ensure a breadth of disciplinary expertise across a range of sub-topics, grouped broadly into energy supply, energy demand, carbon dioxide removal (CDR), and experts with cross-cutting or whole systems expertise. We then selected across diversity criteria for gender, ethnicity and career stage. For the wider stakeholder community, participants were identified using a mapping of ‘Key Players’ from Mendelow’s power-interest matrix [27], aiming for a balance of expertise, of ‘incumbent’ or ‘disruptor’ organisations, and using the aforementioned diversity criteria. Further details of stakeholder recruitment and workshop methodology are found in the supplementary methods.

### 2.2. Workshop structure

As the research coincided with the COVID-19 pandemic, workshops were conducted online via zoom. Discussions were facilitated by the authors with the use of Mural software to share notes. Participants moved between plenary sessions, smaller break-out group sessions, and ‘lone-reflection’ sessions designed to prevent ‘group-think’. The workshops were structured as follows:

Round 1: Researchers were split into break-out groups according to expertise and taken through sessions designed to elicit scientific knowledge on

the priorities, processes and conditions for delivering NZ, explore the level of consensus, and knowledge gaps.

Round 2: Stakeholders responded to the priorities and themes which emerged from Round 1, discussed the opportunities and challenges they faced in transitioning to NZ, and developed common priorities and messages back to the research community.

Round 3: Researchers, now in different groups to Round 1, reflected on outputs of the past workshops, provided input on any gaps which had been identified, and discussed the role of research in progressing this.

### 2.3. Data analysis

All workshops were recorded, transcribed, and anonymised. Following each round, a qualitative thematic analysis was undertaken to surface cross-cutting themes which formed the basis of discussion in the following workshops. This analysis involved a process of familiarisation with the data, the bottom-up generation of initial codes, searching for themes, and reviewing and naming themes [27]. At the end of data collection, further analysis was carried out to compare themes from each round, assess the extent of consensus or disagreement around key areas and explore the extent that themes could be constructed into a single overarching narrative [28].

## 3. Results

From this analysis, we present 12 ‘conditions’ for delivering NZ; cross-cutting themes which participants identified as central considerations for achieving rapid emissions reductions. Whilst in no particular order, these conditions fall under four themes described in table 1; acting now, consider communities and place, just transition and whole systems and collaboration. Each condition communicates relevant messages to multiple groups including public, private and third sector stakeholders, funders of research, and the research community itself.

### 3.1. Acting now

#### 3.1.1. Act now to deploy ‘low regret’ solutions on a large scale

There are a range of solutions that participants characterised as ‘low regret’, technologically ‘ready to go’, and able to provide immediate reductions to cumulative emissions. This includes improving building efficiency, deploying heat pumps and district heating networks, electrifying transport systems, expanding infrastructure and access to public and active transport, decarbonising and expanding the electricity system, and implementing certain land-based CDR techniques. Participants expressed a sense of urgency to accelerate the speed and scale of deploying solutions, shifting priorities from the innovation

of new technologies towards ‘large scale programme implementation’.

#### 3.1.2. To learn from successes and failures, monitor, evaluate and communicate outcomes

To deploy solutions at speed and scale, there is a need for greater acceptance of the potential for some projects to fail. Rather than a barrier, this should be seen as an opportunity to learn how to deploy solutions more effectively, enable replication and avoid repetition of mistakes, making the decarbonisation of different sectors and regions an iterative rather than linear process. To achieve this, there is a need for a ‘good feedback loop’, via the effective monitoring and evaluation of initiatives, and the transparent communication of their outcomes. Research plays an important role in evaluating successes and failures, but the public and private sectors also have a responsibility to deliver transparency on the outcomes of projects they deliver.

#### 3.1.3. Clarify governance structures, expectations and responsibilities

Concern was expressed that in the UK a joined up strategic approach to NZ was currently not evident. Accordingly, government should provide more details on overarching strategy, linked to a regulatory framework which will deliver the necessary reductions in emissions. Multi-level governance is essential for delivering this, including better collaboration across different scales and departments of government. Local government have a strong role for delivering local programmes of work but need more resources, funding and capacity. Overall, it is worth acknowledging that the roles and responsibilities of different actors in delivering NZ is highly complex, and is often oversimplified into roles for government, industry and individuals, whilst overlooking many smaller actors. More research should provide insights into ‘how to govern a rapid transition’.

#### 3.1.4. Upskill and capacity build in the workforce and government

A lack of skilled professionals is a key barrier to accelerating the deployment of solutions. Ambitious programmes of re-skilling are needed both to ensure the necessary supply chains are in place to deliver an NZ economy and to mitigate the negative impacts of job losses in incumbent industries. Equally, capacity building is needed in government to coordinate and implement programmes of work; there were calls for a reversal in the outsourcing and spending cuts which have dominated the delivery of UK public services in recent decades. A lack of resource and funding is a particular barrier for local authorities, which are crucial actors for delivering programmes of work and public engagement.

**Table 1.** Summary of 12 conditions to deliver net zero.

Theme	Number	Condition
Acting now	1	Act now to deploy 'low regret' solutions on a large scale
	2	To learn from successes and failures, monitor, evaluate and communicate outcomes
	3	Clarify governance structures, expectations and responsibilities
	4	Upskill and capacity build in the workforce and government
Consider communities and place	5	Better account for the importance of place and spatial dimensions of the net zero transition
	6	Actively engage communities in the changes taking place
Just transition	7	Realise a just transition
	8	Challenge the role of power and vested interests in downplaying and delaying net zero
Whole systems and collaboration	9	Take an interdisciplinary and whole systems approach
	10	Review the research and innovation funding landscape
	11	Incentivise collaboration and reward impact
	12	Explore competing narratives and transition pathways

### 3.2. Consider communities and place

#### 3.2.1. Better account for the importance of place and spatial dimensions of the NZ transition

Deployment of solutions needs to fit the different social, cultural, economic and technological contexts of different local areas. The benefits and costs of decarbonisation will not be evenly distributed, and a spatial analysis, particularly for industrial restructuring, is needed to help mitigate the negative impacts that some areas may face. NZ scenarios often focus on the national or global scales and overlook geography and local complexities. There is a need for analysis to demonstrate how NZ is delivered on a local scale, both in towns, cities and rural areas.

#### 3.2.2. Actively engage communities in the changes taking place

To continue making emissions reductions, interventions will need to become more visible and require more changes to how people live their lives. Most participants agreed on the principle of actively engaging communities to 'bring people along', communicating better the implications of what NZ means for people's lives, providing a 'vision' of NZ and its co-benefits, alongside communicating the negative consequences of failing to decarbonise. However among participants from the research community, differences were expressed regarding how and whom could deliver this, and how transformative it could be. Some felt that if done effectively, public engagement could generate social momentum and ultimately more political pressure for change. Bottom-up participation in decision making, particularly around place-based solutions to climate change, could help communities shape and have ownership over the changes which impact their lives, which could both increase engagement with NZ and help ensure that programmes are delivered in a just

way. Others were more sceptical about the capacity to develop public support for a wide range of decarbonisation measures when these needed to be implemented rapidly. They felt that prioritising public engagement, particularly when limited to 'tick-box' type consultation exercises, could amount to climate delay, noting that there is already a lack of public support and 'social legitimacy' for the fossil-fuelled status quo.

### 3.3. Just transition

#### 3.3.1. Realise a just transition

Making NZ a 'just transition' is frequently discussed, but there is a need to clarify what this means in practice to avoid it becoming empty rhetoric. Participants discussed justice in relation to a range of concepts, including the fairness of decision making procedures, the 'winners and losers' of economic restructuring, the potential to design a transition which reduces socio-economic inequalities and delivers co-benefits for public health, ecological sustainability and improving access to energy services, and the role of an economic system which currently drives inequality, wealth concentration and excess consumption in generating emissions.

Ensuring decision making processes are perceived as just and creating a transition which mitigates for the spatial injustices which arise from economic restructuring were seen as important conditions for achieving NZ. The inequality of economic distributions was a more controversial area where different viewpoints emerged. Stakeholders saw delivering co-benefits, particularly for those in energy poverty, as a core element of delivering NZ. Others felt that while important, a narrow framing of a just transition around co-benefits and poverty overlooks the need to transform excess energy use and associated emissions from the wealthy. They felt that a core condition for delivering NZ is addressing high

consumption lifestyles, and for some, a fundamental change to economic systems currently predicated on growth and wealth concentration. However, others felt that aligning NZ with political arguments around the injustice of wealth inequality poses a risk to the political consensus around NZ and potentially undermines progress. Ultimately, justice considerations were considered central to the delivering of NZ, despite a lack of consensus on the implications of this in practice. More attention should be paid by both the research community and decision makers to clarify the implications of a just transition and help realise this.

### *3.3.2. Challenge the role of power and vested interests in downplaying and delaying NZ*

There are institutions and individuals downplaying the possibility for technological and social transformations. Pushback from powerful vested interests poses a serious risk to delivering NZ, and this should be explicitly recognised, its impact identified and action taken where appropriate. Lobbying both from incumbent industries who have financial interests in delaying a rapid transition, and less visible ‘dark’ lobbying by political actors, pose a significant risk. There was not an agreed role for incumbents or approach for dealing with vested interests which seek to delay NZ, however this is a crucial, often overlooked issue and represents a gap in many NZ narratives.

### *3.3.3. Take an interdisciplinary and whole systems approach*

To achieve NZ, systemic changes are needed to socio-technical systems. Participants felt that narratives should not overemphasise the role of elements of change without placing them within the whole system. For example, there is a risk that prominent NZ narratives overemphasise the role of technology without discussing the need for social and cultural change, focus on the decarbonisation of energy supply whilst overlooking demand, and overemphasise the responsibility of individuals or of the state whilst oversimplifying the complex interactions of different actors operating in an overarching system. Instead, there is a need to take a whole systems approach to planning and delivering NZ. This applies both to government decision making, where ‘siloed’ policy making across different departments and scales of government prevents whole systems thinking, and to the private sector, third sector and research, where interdisciplinary collaborations can help to understand the interactions between different sectors and different types of solutions, and help to uncover whole systems solutions. Academia is uniquely positioned to carry out work to understand how whole systems change can be delivered, however this needs to be better funded and supported within academic institutions and through research funding.

### *3.3.4. Review the research and innovation funding landscape*

Research plays a crucial role in providing the evidence needed to guide a rapid transition to NZ, and it is important that funding reflects this. The climate change research funding landscape is messy and not effectively coordinated across funders to ensure that research aligns with the urgency of delivering NZ. There is a need to ‘take stock’ and review where knowledge has been produced (to avoid replication), how it can be disseminated, and where there are gaps. Funders should address the imbalance identified by participants regarding the types of research which receive more funding, in particular the focus on blue-sky research and novel supply-side technologies. More funding needs to be targeted towards application and implementation-based research, demand side solutions, the interactions between sectors, social science and governance issues.

### *3.3.5. Incentivise collaboration and reward impact*

Effective collaboration between the public sector, private sector and the research community is an important condition for delivery. Collaboration and the co-production of knowledge is a valuable way to increase the impact of research, but academic institutions undervalue the importance of broader engagement needed to achieve NZ targets. Institutional change is needed to provide incentives and time for researchers to take part in engagement activities which deliver a meaningful impact on the NZ challenge. Currently, effective collaboration is often dependent on personal networks and therefore can be limited to those with already well-established careers and contacts. Large research centres with built in structures for engaging with stakeholders, for example funded positions for knowledge exchange specialists or secondment opportunities could be one way of tackling this. Researchers should look to collaborate with actors where there is the greatest potential to deliver meaningful change; some suggested looking beyond traditional collaborations with industry and the public sector to collaboration with activist organisations which have had a significant impact on shifting the climate agenda.

### *3.3.6. Explore competing narratives and transition pathways*

Finally, whilst our workshops were designed to explore the level of consensus around conditions for delivering NZ, there were a number of areas which remained contentious throughout the process and revealed some fundamentally opposing perspectives. Participants discussed different narratives regarding the pace and nature of change necessary to achieve NZ, for example around issues of economic growth, and the feasibility of delivering more radical solutions on a short time scale. The prominence of these contentions around fundamental issues in the NZ

transition held by both experts and key stakeholders highlight the need to continue examining contested areas and bringing together stakeholders with opposing views.

#### 4. Discussion

This research brought together diverse groups of experts and stakeholders to deliberate on the key actions and conditions necessary to deliver a rapid transition to NZ in the UK. While the data generated was extensive and diverse, our analysis distils 12 conditions for delivering NZ which cut across sectors and disciplines. Taken together, they can guide strategy, decision making, and future research agendas in climate change mitigation.

Whilst recognising the importance of continuing to deliver technological innovation, the workshops did not simply generate a list of technologies to be deployed, but instead produced a complex web of conditions which recognise the complexity of the socio-technical systems that low carbon technologies are embedded in. These issues are not new ideas and have been debated by experts for many years. However, the workshops highlight that these knotty governance challenges are at the crux of progress towards emissions reductions, despite often receiving less attention. Progress towards NZ in many countries has been fragmented and the limited range of fuel switching and energy efficiency measures delivered are insufficient to meet climate commitments. Therefore, this research acts as a reminder to foreground these conditions in efforts to decarbonise and demonstrates the need to refocus efforts to explore their solutions.

Bressand and Ekins have recently called for greater research attention to be given to the construction and maintenance of energy transition discourses in the European public sphere [29]. In our workshops, underlying many of these points were two somewhat different ways of thinking about the problem of NZ. On the one hand, some participants felt NZ could be achieved without overhauling existing institutional and economic structures, which they saw as slow-moving and conducive to fragmented change, whilst others felt that the only way to achieve NZ in the timeframes available was to activate processes of rapid and transformative change, including de-growth and an end to unsustainable consumption practices. As Bressand and Ekins also argue, a deeper analysis of the motivations and values behind such narratives is needed, which goes beyond the bounds of this paper. However, the presence of this disagreement reiterates the need to use interdisciplinary research to explore competing pathways, and understand why different narratives of NZ arise. It shows that the highly complex problem of NZ will likely have clumsy solutions which do not neatly fit into one world view, warranting the need to consider different possible

pathways when designing decarbonisation strategies. Analysis of policy discourses in both the UK [30] and Europe [31] show that the evidence which plays into policy decisions is restricted to the first perspective: it sits within a green growth paradigm, is risk adverse and assumes limited feasibility of transformative social and economic change. The deliberative and consensus building processes used here can be a valuable tool to open up the possibility of a broader range of transition pathways and reveal the limitations of decision making which relies on a single world view. Such processes could be an important part of generating the evidence used to make NZ policy decisions.

This research also offers a range of insights into how the research community can accelerate the transition to NZ. Participants recognised the need to align research with the delivery of NZ, calling for changes to both institutional norms and funding priorities which align with other calls to reform the science-policy knowledge architecture to more effectively guide sustainability transitions [32]. To deliver research which can provide meaningful impact on NZ, funding priorities should shift from a focus on novel decarbonisation technologies to developing empirical evidence for how solutions can practically be implemented, including place-based considerations, the implications in terms of fairness, co-benefits and trade-offs, the roles of different actors, and developing methodologies to evaluate the effectiveness of different solutions. Several issues which remained highly contested in our workshops also present future research agendas; broadly speaking, these relate to the necessity and feasibility of pursuing an NZ pathway involving rapid social and technical transformations and a new economic system without the pursuit of economic growth.

Participants from both the research community and other sectors recognised the need to expand the networks of stakeholders involved in research, so that more collaborative research is undertaken with a broader range of actors which can offer new routes to creating impact. Finally, the need to bring together interdisciplinary approaches to offer a whole systems perspective on NZ was widely supported. Exercises like this project, which brought together researchers from different disciplines for several days of workshops, can provide one avenue to deliver this.

#### 5. Conclusion

This study identified 12 conditions which, to varying degrees, have relevance to different countries, sectors and decision makers when considering rapid transitions. Taken together, they can guide decision making and future research agendas in climate change mitigation. Failure to consider these underlying conditions could mean the likely failure to reduce emissions rapidly and effectively, undermining the wealth

of investment in evidence and knowledge generation thus far. Similarly, continuing climate change mitigation research without considering the underlying system which should be receiving this evidence could be a fruitless activity. This research has presented a broad, whole systems interdisciplinary research agenda which is needed to understand how these conditions could be achieved and their implications for different NZ solutions, which should be reflected in funding priorities.

### Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: <https://reshare.ukdataservice.ac.uk/>. Data will be available from 01 January 2024.

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### Ethical approval statement

Ethical approval for this project was granted by the University of Leeds Research Ethics Committee, reference number: AREA 20-057—Delivering Net Zero, The Role of Research.

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### References

- [1] IPCC 2022 Summary for policymakers *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* ed P R Shukla *et al* (Cambridge: Cambridge University Press)
- [2] Department for Business, Energy and Industrial Strategy 2021 UK Enshrines New Target in Law to Slash Emissions by 78% by 2035 (available at: [www.gov.uk/government/news/uk-enshrines-new-target-in-law-to-slash-emissions-by-78-by-2035](http://www.gov.uk/government/news/uk-enshrines-new-target-in-law-to-slash-emissions-by-78-by-2035)) (Accessed 10 October 2022)
- [3] Barrett J *et al* 2022 Energy demand reduction options for meeting national zero-emission targets in the United Kingdom *Nat. Energy* **7** 726–35
- [4] Dooley K, Christoff P and Nicholas K A 2018 Co-producing climate policy and negative emissions: trade-offs for sustainable land-use *Glob. Sustain.* **1** e3
- [5] Brand C, Anable J, Ketsopoulou I and Watson J 2020 Road to zero or road to nowhere? Disrupting transport and energy in a zero carbon world *Energy Policy* **139** 111334
- [6] Garvey A, Norman J B and Barrett J 2022 Technology and material efficiency scenarios for NZ emissions in the UK steel sector *J. Clean. Prod.* **333** 130216
- [7] Winkler M, Kattirtzi M, Lowes R, Woodman B and Poulter H 2019 Disrupting the UK energy system: causes, impacts and policy implications *UKERC* June p 40
- [8] CCC 2022 Progress in reducing emissions: 2022 Report to Parliament (available at: [www.theccc.org.uk/publications](http://www.theccc.org.uk/publications)) (Accessed 10 October 2022)
- [9] Nelson S and Allwood J M 2021 Technology or behaviour? Balanced disruption in the race to NZ emissions *Energy Res. Soc. Sci.* **78** 102124
- [10] Pourmirza Z, Hosseini S H R, Walker S, Giaouris D and Taylor P 2022 The landscape and roadmap of the research and innovation infrastructures in energy: a review of the case study of the UK *Sustain* **14** 7197
- [11] Engineering and Physical Sciences Research Council 2020 Impact of the Energy Research Programme (available at: [www.ukri.org/wp-content/uploads/2021/10/EPsrc-201021-ImpactEnergyResearchProgrammeAggregateReport-V2.pdf](http://www.ukri.org/wp-content/uploads/2021/10/EPsrc-201021-ImpactEnergyResearchProgrammeAggregateReport-V2.pdf)) (Accessed 10 October 2022)
- [12] Institution of Engineering and Technology 2021 Energy Technologies for NZ: An IET Guide (available at: [www.theiet.org](http://www.theiet.org)) (Accessed 10 October 2022)
- [13] Tvinnereim E and Mehling M 2018 Carbon pricing and deep decarbonisation *Energy Policy* **121** 185–9
- [14] Hall L M H and Buckley A R 2016 A review of energy systems models in the UK: prevalent usage and categorisation *Appl. Energy* **169** 607–28
- [15] Dixon J, Bell K and Brush S 2022 Which way to NZ? a comparative analysis of seven UK 2050 decarbonisation pathways *Renew. Sust. Energy Transit.* **2** 100016
- [16] Levenda A M, Behrsin I and Disano F 2021 Renewable energy for whom? A global systematic review of the environmental justice implications of renewable energy technologies *Energy Res. Soc. Sci.* **71** 101837
- [17] Sovacool B K, Baum C M, Low S, Roberts C and Steinhilber J 2022 Climate policy for a net-zero future: ten recommendations for direct air capture *Environ. Res. Lett.* **17** 074014
- [18] Sovacool B K, Bazilian M D, Kim J and Griffiths S 2023 Six bold steps towards net-zero industry *Energy Res. Soc. Sci.* **99** 103067
- [19] Varho V and Huutoniemi K I 2014 Envisioning solutions: expert deliberation on environmental futures *Transdisciplinary Sustainability Studies: A Heuristic Approach* ed K Huutoniemi and P Tapio (Routledge) pp 140–57 (available at: <https://helda.helsinki.fi/handle/10138/235187>)
- [20] Willis R, Curato N and Smith G 2022 Deliberative democracy and the climate crisis *Wiley Interdiscip. Rev. Clim. Change* **13** e759
- [21] Guston D H and Sarewitz D 2002 Real-time technology assessment *Technol. Soc.* **24** 93–109
- [22] Pidgeon N 2020 Engaging publics about environmental and technology risks: frames, values and deliberation *J. Risk Res.* **24** 28–46
- [23] Renn O, Webler T and Wiedemann P 1995 *Fairness and Competence in Citizen Participation: Evaluating Models for Environmental Discourse* (Heidelberg: Springer) (<https://doi.org/10.1007/978-94-011-0131-8>)
- [24] Devaney L, Torney D, Brereton P and Coleman M 2020 Ireland's citizens' assembly on climate change: lessons for



- deliberative public engagement and communication  
*Environ. Commun.* **14** 141–6
- [25] Elstub S, Carrick J, Farrell D M and Mockler P 2021 The scope of climate assemblies: lessons from the climate assembly UK *Sustain* **13** 11272
- [26] Neef R, Verweij S, Busscher T and Arts J 2020 A common ground? Constructing and exploring scenarios for infrastructure network-of-networks *Futures* **124** 102649
- [27] Mendelow A L 1981 Environmental scanning—the impact of the stakeholder concept *ICIS 1981 Proc.* (17 October 2022) (available at: <https://aisel.aisnet.org/icis1981/20>)
- [28] Braun V and Clarke V 2006 Using thematic analysis in psychology *Qual. Res. Psychol.* **3** 77–101
- [29] Bressand A and Ekins P 2021 How the decarbonisation discourse may lead to a reduced set of policy options for climate policies in Europe in the 2020s *Energy Res. Soc. Sci.* **78** 102118
- [30] Smith S R and Christie I 2021 Knowledge integration in the politics and policy of rapid transitions to NZ carbon: a typology and mapping methods for climate actors in the UK *Sustainability* **13** 662
- [31] Samper J A, Schockling A and Islar M 2021 Climate politics in green deals: exposing the political frontiers of the european green deal *Politics Gov.* **9** 8–16
- [32] Oliver T H *et al* 2021 Knowledge architecture for the wise governance of sustainability transitions *Environ. Sci. Policy* **126** 152–63