Received: 7 May 2023 | Revised: 11 March 2024 | Accepted: 18 March 2024

DOI: 10.1002/geo2.139

ARTICLE

Imagining and emplacing net zero industrial clusters: A critical analysis of stakeholder discourses

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Funding information
UK Research and Innovation, Grant/Award Number: EP/V027050/1

Abstract

Decarbonizing industrial sectors is a critical global challenge, involving the creation of new industrial spaces—'net zero industrial clusters'—co-locating energy sectors and 'hard-to-abate' industries such as oil refining and steelmaking. This paper provides the first empirically grounded geographical investigation of these emerging spaces. It employs a place-based research agenda to unpack how UK net zero industrial clusters (ICs) are imagined and emplaced in policy and industry discourses through place-based naming, spatial configuring and mapping activities. By conducting document analysis, 33 in-depth stakeholder interviews and five field trips to three UK case studies, we show how cluster imaginaries vary across cases and policy contexts in terms of constituents, focus and purpose. Ontological complexity is compounded by different rationales among stakeholders in configuring clusters and by contested cluster naming and boundary setting. This ambiguous, evolving spatiality raises important political and justice concerns over who and where is excluded in cluster building. These findings advance the geographies of low-carbon transitions by showing: (1) ways that ICs' spatial embeddedness, which underlies cluster spatial configurations, helps increase industry actors' recognition of their economic, social and cultural ties with the places of their making, even if this risks path dependency; (2) how fluid cluster boundaries, reflected in cluster names and maps, emphasize the value of a network topology of scale to enable spatially inclusive, multi-scalar climate mitigation. Finally, we argue that a place-sensitive net zero policy mindset is vital for fulfilling ICs and the UK's decarbonization potential in a manner that is both fair and locally grounded.

KEYWORDS

energy geographies, geography of sustainability transitions, industrial clusters, industrial decarbonization, net zero, place-based approach

This work was supported by the UK Research and Innovation (UKRI) Industrial Strategy Challenge Fund (ISCF) Industrial Challenge as part of the UK Industrial Decarbonisation Research and Innovation Centre (IDRIC) award number EP/V027050/1.

1 | INTRODUCTION

Low-carbon transitions are geographical processes (Bridge et al., 2013) which involve dynamic socio-technical reconfigurations across places and scales along with changes in the physical environment, social relations and economic conditions of a place. Recently, policy and research attention across the world has been directed to the industrial sector, which accounts for approximately one quarter of global greenhouse gas (GHG) emissions and has to decrease by 25.5% by 2030 to achieve the 2050 Net Zero Emission Scenario (IEA, 2022). How to deploy net zero technologies and infrastructures—such as hydrogen gas, carbon capture utilization and storage (CCUS) technologies and renewable energies—to enable a low/zero-carbon industrial transition becomes a pressing challenge (Edwards et al., 2021; IPCC, 2023).

One common solution is to create net zero industrial clusters. Several high-emitting industrial areas in Europe, America and East Asia, such as the Port of Rotterdam, have received government funding to carry out pilot projects (Rattle & Talyor, 2023). These 'clusters' and 'hubs' for industrial decarbonization can go beyond energy transitions and existing industrial clusters by connecting up a wide range of energy-intensive industries (such as oil and gas refining, steelmaking and petrochemicals) across several locations with hydrogen or/and CCUS-based megaprojects (Sovacool & Geels, 2021).

These efforts to decarbonize industrial regions pose an intriguing research topic for geographers on low-carbon transitions that, to date, have mainly paid attention to the decarbonization of single socio-technical systems such as energy. It raises important questions regarding how geographical scales (e.g. national industrial policies, regional projects and local actions) as well as diverse places and spaces (including pipeline networks that spread across non-industrial areas and under the sea) are implicated in and shape pathways of industrial decarbonization. Despite a growing recognition of the need to consider spatial dimensions of industrial decarbonization (Carr-Whitworth et al., 2023; Devine-Wright, 2022; Lewis et al., 2023), including implications for just transitions (Eadson et al., 2023; Upham et al., 2022) and the shaping of cluster forms (Rattle & Talyor, 2023), there is a lack of empirical research on fundamental questions concerning what kind of new industrial spaces are imagined and how these imaginaries are emplaced through discourses and technology deployment.

This paper aims to address this important gap by providing the world's first empirically grounded geographical investigation of net zero industrial spaces emergent in cluster formation, using rigorous comparative research designed to unpack the ways in which they are conceived in policy and industry discourses. The UK's competitive cluster approach for industrial decarbonization constitutes a useful example. Since 2018, the UK government has adopted a cluster approach to encourage competition between industrial decarbonization projects, with an aim to establish four low-carbon industrial clusters (hereafter ICs) by 2030 and the world's first net zero IC by 2040. Six ICs across the country have been funded since 2020 to deliver region-based solutions from the mid-2020s. This approach 'align[s] decarbonization with broader social goals' (Bridge & Gailing, 2020, p. 1037), including transforming key industrial regions into 'SuperPlaces' with the deployment of CCUS and hydrogen infrastructures (HMG, 2020). While indicating some awareness that 'places can be "re-made" during a transition' (Murphy, 2015, p. 83), the spatial meanings and implications of these ICs are yet to be fully scrutinized.

Drawing on a place-based research agenda that foregrounds key issues of ontology, place-making, and sense of place (Devine-Wright, 2022), this paper conducts analysis of cluster discourses by emerging coalitions of actors, which is particularly appropriate as UK ICs are largely at the planning stage. With evidence drawn from three case study ICs in England, Wales and Scotland, it addresses three questions: (1) How are net zero ICs imagined in policy and industry discourses? (2) How are these cluster imaginaries emplaced in specific contexts through place-based naming, spatial configuring and mapping activities? (3) What are the implications of the findings for critically understanding evolving 'place-based' policies on net zero industrial transitions, both in the UK and globally?

This paper demonstrates how the imagining and emplacement of net zero ICs (including their boundaries, centres and place-based names) are not self-evident, but diverse, constantly evolving and often contested. With these findings, this paper advances a more sophisticated reading of spatial embeddedness and (re)scaling in the multi-sector transition process, including their implications for just transitions and the importance of a network topology of scale in accelerating an inclusive climate mitigation. It also reveals the politics and discursive tactics employed by cluster stakeholders to produce new industry spaces. Practically, this paper demonstrates that the predominant technocentric perspective in policy discourses overlooks the fluid spatiality of ICs and alternative cluster imaginaries. This deficiency compromises the potential for policy to encourage diverse and inclusive decarbonization strategies that emerge from and for different spatial contexts. We conclude by recommending a place-sensitive approach to industrial decarbonization policies in and beyond the UK that can be conceived as genuinely place-based, fair, and attentive to the fluid spatiality of net zero industrial transitions.

This paper is structured as follows: Section 2 outlines our theoretical framework based on literatures on the place and geographies of low-carbon transitions. Section 3 introduces the methodology and three cluster cases. Sections 4 and 5 present findings, whose theoretical and policy implications are discussed in Section 6. The paper concludes with directions for future research to enrich the socio-spatial understandings of industrial transitions (Sovacool et al., 2023).

2 | THEORETICAL FRAMEWORK

To investigate the emerging spaces of industrial decarbonization with a fresh perspective, we seek inspiration from geographical research on low-carbon transitions, especially the concept of place. In so doing, this paper diverges from rich discussions on 'industrial clusters' in economic geography and regional studies (Cruz & Teixeira, 2010; Lazzeretti et al., 2014; Rocha et al., 2020; Vorley, 2008).[1] While recognizing the shared emphasis on productivity, economic growth and innovation, and the involvement of some traditional 'industrial clusters' in forming ICs, we argue that a distinction between the two is important to unpack emergent net zero industrial spaces, as they may follow a spatial logic different from that of traditional 'industrial clusters'.

Geographers on low-carbon transitions have called for a relational understanding of transition-prompted spaces. Such a transition space is 'actively constituted through social and material relations' (Castán Broto & Baker, 2018, p. 3). It is not confined to clear-cut territorial boundaries (Massey, 2005), nor is it fixed to a particular scale, such as cities (Binz et al., 2020; Coenen et al., 2012; Coenen & Truffer, 2012; Raven et al., 2012). Scholars have demonstrated that socio-spatial embeddedness matters to sustainability transitions, as contextual conditions (e.g. geographical proximity, institutional and bio-physical settings) help shape the development of innovative technologies and the trajectories of socio-technical systems (Binz et al., 2020; Hansen & Coenen, 2015; Truffer et al., 2015). In parallel, energy geographers have emphasized the spatial reconfigurations of energy systems and related social relations triggered by transition processes (Becker et al., 2016; Bridge et al., 2013; Calvert, 2016; Huber, 2015; Pasqualetti & Brown, 2014). These spatial reconfigurations can be understood using geographical categories, such as scale and spatial embeddedness (Bridge et al., 2013). Among all these concepts, 'place' is arguably fundamental and formative for the spatial strategies that create new energy spaces, including (re)scaling (Casey, 2008; Gailing et al., 2020).

With these insights in mind, this paper examines the extent to which new industrial spaces (proposed to be) created through the UK government's cluster approach to net zero industrial decarbonization have engaged with the geographical concept of place.

We follow a place-based research agenda to industrial decarbonization that recasts the creation of net zero ICs through the deployment of decarbonization technologies as 'acts of place-making that intentionally transforms particular places that have meaning and significance for the people who live, work and visit there' (Devine-Wright, 2022, p. 5). Adopting a relational perspective, an IC is viewed as a 'place' composed of bio-physical, socio-economic, and political relations that are constantly evolving along with daily activities in situ and their interaction with broader exogenous politico-economic processes (Massey, 2005). This conceptualization allows one to explore fundamental questions about how a net zero IC is discursively constructed and geographically enacted by policy-makers and cluster stakeholders to fulfil climate and socio-economic goals.

The fact that ICs worldwide are at a very early stage necessitates an analytical focus on 'cluster imaginaries', referring to individual and collective imaginations about an IC articulated through language, images and texts, including how it is conceptualized, represented and envisioned to take place in specific contexts. Cluster imaginaries as place-based imaginaries of industrial futures exemplify the co-construction of spatial and socio-technical imaginaries (Chateau et al., 2021). Spatially speaking, they invoke and contribute to 'stories and ways of talking about places and spaces' (Watkins, 2015, p. 509), with an aim to transform specific industrial areas into a general, idealized kind of space that meets the needs of low-carbon industrial development. Socio-technically speaking, they can add up to 'collectively held and performed visions of desirable futures' (Jasanoff, 2015, p. 19) attainable through the deployment of decarbonization technologies. These visions, in turn, guide policy commitments and resource allocation to technologies, projects and innovation pathways (Jasanoff & Kim, 2009) that match certain place visions (Kuchler & Bridge, 2018; Levidow & Papaioannou, 2013). In this sense, cluster imaginaries provide a useful lens for unpacking the ways in which net zero industrial transitions are imagined by policy and industry stakeholders to take and remake place.

In this paper, we adopt the first two analytic pillars suggested by Devine-Wright (2022) to explore the imagining and emplacement of cluster imaginaries. First, one can examine the 'ontology' of industrial decarbonization by looking at how ICs are imagined by policy-makers and cluster stakeholders, with a particular interest in space-related discourses of technology deployment. Unpacking cluster imaginaries is fundamental, as they inform what policy-makers and stakeholders mean by using the term industrial cluster, and what they deem as the key constituents, focus and purposes of new industrial spaces that enable (and are reshaped by) decarbonization. The conceptualization of ICs can also affect their materiality by providing guidance for cluster formation as well as discouraging the development of alternative cluster imaginaries and strategies for industrial decarbonization.

Second, one can examine ICs as forms of 'place-making', namely, how the place is invoked, remade and unmade discursively and materially by the introduction of new infrastructures and the modification of existing facilities. In this paper, we focus on the discursive emplacement of ICs, especially the ways in which they are named, mapped and spatially structured in and beyond the proposed 'cluster regions' (i.e. the places in which they are claimed to be anchored). We assume that cluster maps help enact the materialization of cluster imaginaries by illustrating the new spatial orders that are (to be) created by decarbonization projects in specific contexts (Castán Broto & Baker, 2018). This implies adopting a performative ontology of discourses that sees cluster imaginaries as 'embodied performances by people in the material word' rather than just a representation of the material reality about a place or a socio-technical scenario (Ballo, 2015; Watkins, 2015, p. 509). Analysing the performative function of a cluster imaginary contextualizes its development in the interaction with material elements, actors and politico-economic relations that co-shape a place. In so doing, one can investigate the spatiality of net zero ICs (i.e. how their 'interlinked elements occupy locations in space') (Bridge et al., 2013, p. 334), associated political dynamics and strategies in their formation and unpack the likely plural pathways for industrial decarbonization emerging in diverse institutional and geographical settings.

This paper extends the place-based research agenda (Devine-Wright, 2022) by combining it with insights from geographies of low-carbon transitions and by linking it to economic geographies of path creation in industrial regions (Binz et al., 2016; Dawley et al., 2015; Isaksen, 2015; MacKinnon et al., 2019). In terms of path creation, industrial decarbonization can be seen in a socio-historical perspective as the latest wave of industrial restructuring going on in places that have witnessed several boom-bust industrial cycles. It also presents an opportunity for green path development, involving 'both the rise of new green growth paths [...] and the "greening" of existing industries' (Trippl et al., 2020, p. 189) that will remake industrial regions. Unpacking the ontological and place-making implications of ICs can thus shed light on the key actors (firm and non-firm, regional, and extra-regional), assets (natural, infrastructural, human, institutional endowments, etc.), and path development mechanisms (e.g. renewal, diversification and importation) that are mobilized for the creation of net zero industrial regions.

In summary, this paper explores the ontology and place-making of ICs by examining the diverse ways in which they are imagined (Section 4) and emplaced through place-based naming, spatial configuring, and mapping (Section 5) in policy and cluster discourses. Such an exploration, we suggest, can pave the way for future empirical investigations worldwide regarding how low-carbon industrial transitions and regional development may unfold spatially through the development of net zero clusters.

3 | METHODOLOGY & CASE DESCRIPTIONS

3.1 | Policy context and case study selection

UK policy-makers have pioneered in utilizing clusters as the key unit to drive and accelerate the development of decarbonization technologies—especially CCUS and hydrogen—across industrial areas (Hudson & Lockwood, 2023; Sovacool et al., 2022). After the identification of CCUS by the UK government as indispensable for industrial decarbonization in 2017 (BEIS, 2017), a cluster approach was officially employed in the 2018 CCUS Action Plan (Industry Strategy, 2018) and endorsed by the Climate Change Committee report in 2019, which encouraged the UK government to announce the legally binding net zero target by 2050.

The *Ten Point Plan for a Green Industrial Revolution* in 2020 further consolidated this approach by setting out the aim to produce 5 GW hydrogen by 2030 and to capture 10 $MtCO_2$ per year by 2030 through establishing CCUS in two ICs by the mid-2020s and another two by 2030. It also recasts the investment in these decarbonization technologies as enabling both post-COVID-19 economic recovery and social inclusion (e.g. to 'level up our country and enable our proud industrial heartlands to forge the future once again', HMG, 2020, p. 1). The alignment of socio-technical visions for industrial low-carbon transitions and socio-spatial objectives for balanced regional development became a motif in the *Industrial Decarbonization Strategy* (HMG, 2021a) and policy discourses that followed. The carbon capture ambition was increased to 20–30 $MtCO_2$ in 2021 (HMG, 2021b) and the hydrogen target doubled to 10 GW in 2022 (BEIS & PMO, 2022) in response to energy security concerns after Russia invaded Ukraine.

At least six ICs in the UK have been identified and funded by the government (see Figure 1). We considered a comparative study of multiple cases of most benefit to explore the characteristics of new industrial spaces. A comparative research design is adept to trace unfolding processes like industrial decarbonization across sites, actors and time periods (Bartlett & Vavrus, 2017). We selected three ICs anchored in England (the North West Cluster, hereafter NW), Wales (the South Wales Industrial Cluster, hereafter SWIC), and Scotland (the Scottish Cluster, hereafter SC). This selection was based on the relevance of these cases to the research focus (Della Porta, 2008) and to use different geographical and political contexts to obtain a relatively holistic understanding of the cluster approach.

3.2 | Methods of data collection and analysis

To understand the imagining and emplacement of ICs, this research involved an in-depth and extensive data set built upon a variety of well-founded qualitative methods. First, we conducted a detailed document analysis of cluster discourses with NVivo coding software, focusing on key materials updated to mid-June 2022 (including six websites, four webinars, around 40 press releases, and 19 non-technical reports of the studied ICs). These materials were selected for their relevance to the geographical formation and the promotion of the ICs. Knowledge of the cluster regions and discourses obtained from this secondary data analysis, supplemented by a close reading of 16 policy documents, formed the basis for the interview questions.

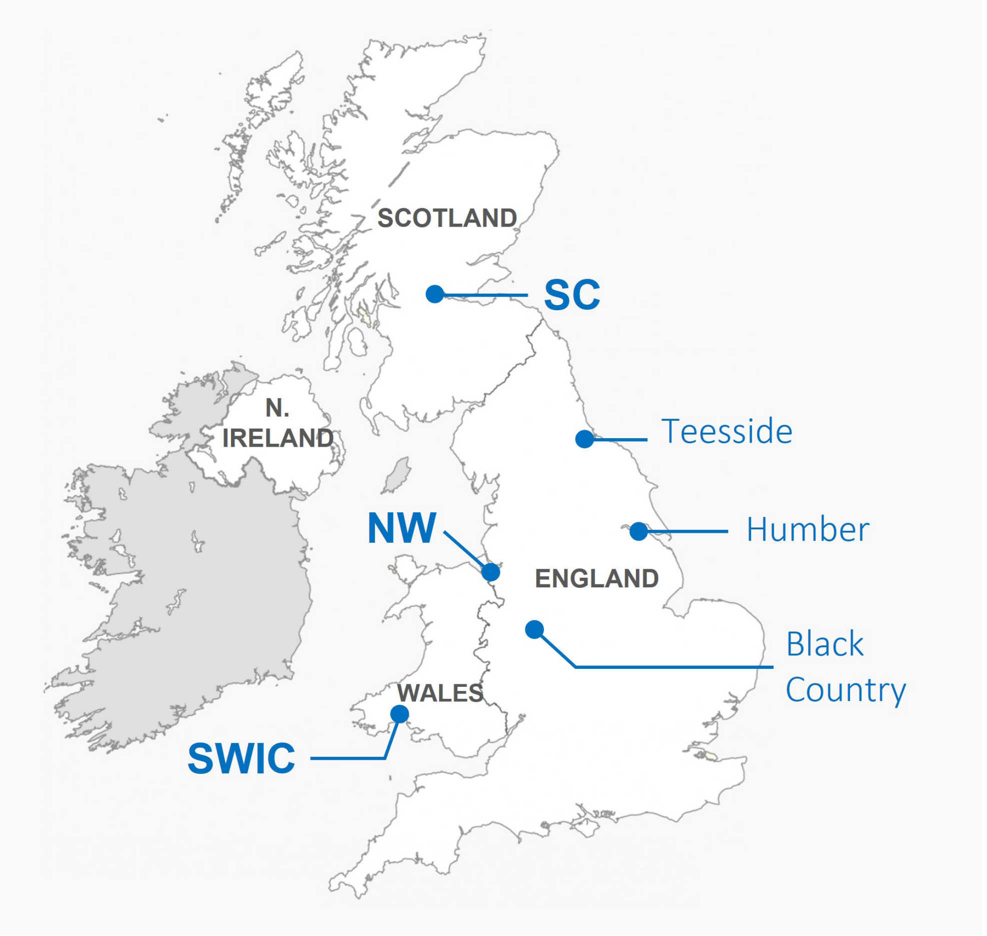

FIGURE 1 A map of the three case studies (marked in bold) selected out of the six ICs across three nations (Scotland, England, and Wales) that were funded by the Industrial Decarbonization Challenge (IDC). Note that the blue dots are illustrative and do not refer to the absolute locations of these clusters.

Second, to obtain insider knowledge about cluster development, we conducted 33 in-depth interviews with cluster stakeholders (on average lasting for approximately 1 h), drawing on these data-informed questions, from late July to late November 2022. Additionally, we selected 4–5 most circulated and/or informative maps from the documents of each case (see Appendix 1). We then used these maps to enable a more interactive discussion about their geographical connotations by inviting informants to describe the boundaries, core areas and changes of these ICs over time besides giving general comments on these maps.

In total, 31 informants gave their consent to participate in the research, representing a wide range of actors engaged with cluster formation (see Appendix 2). Interviews were recorded, transcribed and went through a thematic analysis (Braun & Clarke, 2006) by the first author in the guidance of the three pillars of the place-based research agenda (Devine-Wright, 2022), which allowed her to observe emerging themes and how they were referred across the data set without being limited by discussions in the relevant literature. The primary analysis was then discussed with the second author, whereby overarching themes and patterns were identified to form the arguments of the paper. We considered thematic analysis more suitable for the research than discourse analysis, whose stress on power dynamics between informants (Johnson & McLean, 2020) is outside the focus of this research. The informants' names were replaced with codes (e.g. NW3 for the third interviewee in the North West Cluster) and their affiliations were removed when cited in the paper to protect their privacy.

Last, to obtain first-hand knowledge of these ICs' spatial contexts, five field trips were carried out by one or both authors. These field trips (ranging from 2 to 5 days) covered several key industrial areas in the three clusters, including Newport, Cardiff, Barry, Port Talbot, and Milford Haven in South Wales; Ellesmere Port, Chester, and Runcorn in North West England; and Grangemouth in Scotland.

The findings presented in the following sections are primarily based on the interview data, supplemented with cluster documents, especially on ontology (Section 4) and spatial configurations (Section 5.2). All data were triangulated with the information provided by different stakeholders and the researchers' field observations to obtain a more complete and nuanced understanding of the cases.

3.3 | Case descriptions

The UK government's cluster approach was enacted through two parallel yet overlapping funding programmes associated with the Department for Business, Energy & Industrial Strategy (BEIS): the IDC programme and the CCUS Cluster Sequencing competition (for details, see Appendix 3).[2]

The three cases investigated in the study came into being as the winners of the IDC programme initiated by UK Research and Innovation (UKRI) (Table 1).[3] Largely region-based and industry-led, these IDC clusters are established to 'accelerate the cost-effective decarbonization of industry by developing and deploying low-carbon technologies, especially carbon capture and storage (CCS) and hydrogen fuel switching, at scale in the UK' (UKRI, 2020, para. 1), along with other initiatives on clean energies and energy/resource efficiency. The IDC clusters were also created to boost the productivity and economy of cluster regions.

This IDC programme successfully prompted mobilization and cooperation between industry stakeholders, local/national authorities, trade organizations, and other politico-economic organizations in several regions characterized by an economic reliance on energy-intensive heavy industries. An IDC cluster comprised two parts set by this funding programme—the 'roadmap/cluster plan' and the 'deployment project', which in the three cases were led by different organizations working with a group of often overlapping industrial partners (mostly key emitters in the region) and supporters (especially local authorities and trade organizations). In general, a roadmap/cluster plan, which sets up the overall guidance for regional industrial decarbonization, tends to encompass a wider range of initiatives, types of technologies, and geographical coverage than a deployment project, which tends to emphasize major decarbonization projects in the cluster region.

While each IDC cluster enjoys the freedom to design its decarbonization strategies in accordance with its industrial needs, the CCUS Cluster Sequencing competition launched in 2021 was only eligible for ICs that have deployed large-scale CO_2 pipelines and storage facilities in their delivery plans. This resulted in another set of ICs developing in parallel with the IDC clusters, including the 'HyNet Cluster' anchored on the deployment project of NW and the 'East Coast Cluster' formed by merging the CCUS networks of two IDC clusters in North and North East England. The emergence of these 'Track-1' and 'Track-2 clusters' suggests the flexible and dynamic nature of cluster building as well as ambiguity

TABLE 1 Three IC cases and their status in the two government cluster funding programmes.

Cluster cases	NW	SWIC	SC
Associated regions/nations	North West England and North Wales	South Wales	Scotland
Associated emissions	5.04 $MtCO_2$/year	8.98 $MtCO_2$/year	5.01 $MtCO_2$/year
Key industries and facilities to be decarbonized	Oil-refining, glass, cement, chemicals, manufacturing, etc.	Steel, oil-refining, cement, chemicals, general manufacturing, gas-fired power plants, etc.	Oil-refining, chemical, gas-fired and biomass power plants, etc.
IDC-roadmaps/cluster plans			
Phase 1	The North West Hydrogen and Energy Cluster: Route to Net Zero	South Wales Industrial Cluster	Scotland's net zero roadmap (SNZR)
Phase 2	The Net Zero NW Cluster Plan	South Wales Industry—A Plan for Clean Growth	Scotland's net zero roadmap (SNZR)
IDC-deployment projects			
Phase 1	HyNet Carbon Capture Utilization and Storage	South Wales Industrial Cluster	Scotland's net zero infrastructure (SNZI)
Phase 2	HyNet (offshore & onshore)—Hydrogen and CCUS	South Wales Industrial Cluster	Scotland's net zero infrastructure (SNZI)
CCUS Cluster sequencing	Track-1 winner (HyNet Cluster)	Not eligible for bidding despite great effort in trying	Reserve status for Track-1 Track-2 winner (The Acorn project)

Note: (1) The amount of associated emissions for the three cluster cases follows Pultar and Ferrier (2022). (2) The Acorn project in SC was awarded Track-2 status in July 2023.

in the UK government's conceptualization of ICs. As a result, it is necessary and useful to investigate in further detail the imagining and emplacement of net zero ICs.

4 | IMAGINING ICs IN POLICY AND INDUSTRY DISCOURSES

In order to explore the ontology of cluster-based industrial decarbonization, this section attends to the way in which stakeholders conceived an IC. Our analyses indicate that imaginaries of ICs were not self-evident, but rather diverse, ambiguous, and sometimes contested. This is partly due to the wide range of elements, stakeholders, contexts, and implications linked to industrial decarbonization, and partly associated with the design of government funding programmes that guided—but not determined—cluster formation.

4.1 | Plural ontologies of ICs

Differences in imagining the ICs come from three facets—what a cluster means, what activities it focuses upon and what purposes it aims to achieve (see Table 2).

In line with the policy description of IDC clusters, a cluster often connoted a space of industry-related economic activities that may or may not be concentrated and interconnected. In some cases, a cluster signified a grouping of actors, such as the HyNet cluster, which was distinguished from 'HyNet Land', a spatial imaginary coined to describe the project's territoriality.

The focus of ICs was mostly put on the source of (i.e. emitters) or the solution for (i.e. decarbonization initiatives) industrial GHG emissions. One reason for the spatial ambiguity of ICs stems from the fact that key emitters and decarbonization projects are rarely co-located. For example, the Acorn Project in the SC is based in St. Fergus which has the best access to undersea CO_2 stores but is approximately 200 km away from the largest emission site in Grangemouth. Similarly, key emission sites for the NW cluster were located in North West England, yet the identified undersea carbon storage location is off the coast of North Wales. SWIC goes beyond the source/solution discrepancy by aspiring to create industrial synergies which focus on strengthening the interconnections between all industrial activities and with other sectors. As Section 5.2 will show, these divergent responses to the lack of co-location between key emitters and decarbonization projects influenced the spatial configurations of these ICs.

Although to some extent clusters were deliberately constructed to obtain state funding, most industrial informants considered them pivotal for meeting their technological, political and economic needs in decarbonizing their activities. There was a consensus between policy-makers and industry stakeholders that ICs provided the most cost-effective way to deploy decarbonization infrastructures whose costs and risks were beyond the financial capacity of any single company or sector. By mobilizing resources and expertise from a range of industries in the region, it was also said to boost industry stakeholders' confidence, collaboration and chances in tackling an unfamiliar yet urgent challenge. Conversely, it was considered 'a huge disadvantage to anybody who's not in a cluster' (SWIC5) as 'businesses don't necessarily know where to start or who to talk to' (NW9). Several informants recognized the political need for establishing a united voice of traditionally disconnected and dispersed industries in a region, since 'it would be difficult for UK government to ignore such a coordinated cluster' (SWIC1), while helping ensure that government policy and 'the reality of companies' (SWIC10) are aligned. To attract more political support, industry stakeholders strategically campaigned that clusters could deliver sustainable local economic development, thereby aligning visions for (sub)national industrial decarbonization and the local regeneration of struggling industrial areas.

In this regard, UK ICs can be seen as both a political construct prompted by national government policies and an economic endeavour actively made by local and multinational firms in partnership with local governments, trade organizations and universities. These actors imagined ICs not only as a means for climate mitigation, but also as the most viable way to harness (extra-)regional resources and enable regional and local industrial restructuring required by ambitious climate goals. It involves all three kinds of actors that MacKinnon et al. (2019) identified for regional path creation: 'industrial entrepreneurs' (e.g. industrial members of ICs) who have intentionally deviated from existing fossil fuel-based industrial structures; 'institutional entrepreneurs' (e.g. government partners of ICs) who innovate existing institutional arrangements into one that can support deep industrial decarbonization; and 'place leaders' (e.g. industry-led partnerships with local authorities to develop and promote ICs) that can influence other regional actors with a collective vision to join the call for local industrial decarbonization.

4.2 | Policy-induced complexity

In practice, the different UK government funding competitions (see Table 1) complicated the imagining of ICs and 'confus[ing] everybody right from the start' (SWIC2). During interviews, informants often conflated various projects associated with different funding programmes or referred to merely one (side) of them, depending on their engagement with and knowledge about cluster building.

One major source of confusion in imagining ICs derives from the distinction of 'cluster plans' and 'deployment projects' in the IDC programme, which involved different memberships (though with some overlap) and dimensions of cluster building (planning vs. delivery). While there existed close communications between the cluster leads and key facilitators of the clustering process, not all participants were familiar with or aware of the other parts of the IDC clusters. For instance, an informant who worked solely on the deployment of hydrogen pipelines in NW identified the cluster as 'HyNet in the form of, you know, the boundaries of the project' based on his 'current day-to-day world' (NW4). By contrast, another NW stakeholder who played a key role in the cluster plan insisted that HyNet is just one important project, 'and there is a lot more going on' (NW3).

This tendency to emphasize deployment when imagining net zero clusters also occurred in SC which was largely anchored on the Acorn project. For instance, a stakeholder suggested that 'if you wanted to talk Scottish Cluster, you would probably start with the Acorn partners' (SC4), despite recognizing that the cluster was bigger than the project.

Confusion regarding what and who represents a cluster increased with the CCUS cluster sequencing competition. As mentioned, the candidates for this funding scheme often overlapped with the IDC deployment projects that comprised large-scale CCUS projects. For instance, industry stakeholders associated with the Acorn project in Scotland initiated a 'Back the Scottish Cluster' campaign in 2021 to support their bid for Track-1 status. The imaginary of the 'Scottish Cluster' hence became associated with the 'Track-1 Cluster' closely tied to the Acorn project rather than with the IDC

TABLE 2 Multifaceted and diverse imaginings of 'industrial clusters' in policy and industry discourses.

Facets	Description	Examples from the data
Signified meanings	A collection of *industrial sites* located within certain territorial boundaries that is significant to local and UK-wide economies	'Industrial clusters are areas with a number of industrial sites [...] Clusters are key hubs of local activity and an important part of the UK economy' (Industrial Strategy, 2019, p. 2)
	A grouping of *industrial organizations* who come together to achieve industrial decarbonization in a given locality	'[The HyNet Cluster] refers to all of those guys that are kind of involved in HyNet [project] as organizations.' (NW2)
Focus of activities	Key *emitters*	'The SNZR team mapped these emissions and found that around 80% lie within a corridor highlighted in blue on the map [...] It is these emissions that SNZR is focusing on.' (SNZR, 2020, p. 2)
	Key industrial decarbonization *technologies and projects*	'The cluster must meet the definition of a CCUS cluster, which we define as a T&S network and an associated first phase of at least two CO_2 capture projects.' (BEIS, 2021, p. 14)
	The *synergy* of industries and other sectors within a region	'demonstrating true "systems of systems" thinking, by complementing decarbonization and efficiency of other sectors such as domestic (localized district heat), commercial, agriculture (agritech) and transport (BEV and hydrogen) to meet the societal needs and objectives of the region.' (CR Plus, 2020, p. 7)
Purposes	As the most cost-effective way to decarbonize industry	'if you're going to decarbonize industry, the best way of doing that is to decarbonize a cluster of industry, because it means you need less infrastructure, and you can use that infrastructure for the whole of the region.' (NW2)
	As a promising mechanism to accelerate CCUS/hydrogen deployment	'The development of clusters (i.e. regional groupings where several CCUS facilities share infrastructure and knowledge) and associated Clean Growth Regeneration ("CGR") Zones can help drive lower cost CCUS, unlock value for local economies, and foster continuous technical innovation.' (BEIS, 2018a, p. 5)
	As a unit for applying for government funding	'the cluster is purely a construct of BEIS. The cluster was only created to allow a bid to be made.' (SC2)
	As an important means for industry to increase political leverage	'if we have a combined approach that then gives us a lot more leverage with external parties as well, such as local and national government.' (NW10)
	As an attractive environment for investors	'I think without any of these efforts, South Wales and industries in the UK would probably not be invested in, compared to others that might get more government support, or might just be more investable.' (SWIC4)
	As a driver for economic growth and industrial development	'This will be a major lever to the levelling-up agenda, attracting significant commercial activities to the region and growing and securing new low carbon industries which will then be able to extend their reach globally from a strong base.' (NZNW, 2021, p. 9)
	As a promising way to regenerate industrial areas	'The heart of the project is aimed at achieving net zero and at the same time, reversing the decline of heavy industry and creating economic prosperity for Wales.' (SWIC, 2021)

cluster, whose planning side was called a 'roadmap' (instead of 'cluster plan') to avoid confusion. While projects in both programmes managed to work together, one informant noted the policy-induced difficulty in communicating with other stakeholders: 'I have to always keep in mind they're talking about something slightly different to the Scottish Cluster that I think about as a sort of industry' (SC3).

By contrast, seemingly few tensions arose in SWIC between the deployment and plan dimensions, even though they shared the same name. Informants tended to see this cluster as a combination of both IDC projects and unrelated to the Track-1 cluster competition, for which SWIC was not eligible to bid due to a lack of feasible CO_2 storage.

In short, findings from the three cases suggest that the imaginary of a cluster at the core of the UK's industrial decarbonization approach is not straightforward, unified and fixed. Even if some definitions were institutionally stabilized through state power to guide the creation of clusters, space remained for diverse cluster imaginaries to emerge, compete, and co-exist with each other in line with stakeholders' relations with different policy frameworks. In particular, we found that spatially disparate emission sources and solutions, as well as parallel yet distinct government funding competitions, provided considerable scope for complexity and confusion as to how clusters were imagined across stakeholder communities. This indicates that contestations over socio-technical imaginaries occur not only between multiple state imaginaries (Hess & Sovacool, 2020) or between experts and non-experts (e.g. Smith & Tidwell, 2016; Tidwell & Tidwell, 2018), but also among various interpretations of institutionalized imaginaries as they emerge over time. Understanding the 'parallax' of these ICs (Sovacool et al., 2020) is important, as it facilitates effective communication among policy-makers and cluster stakeholders and helps outsiders (e.g. researchers, investors and public) to identify who to approach for what sort of engagement. As will be shown, relational, plural understandings of cluster imaginaries help reveal the ways in which ICs are emplaced in specific contexts.

5 | EMPLACING ICs

To understand net zero ICs in place-making terms, this section investigates how the three clusters are emplaced in specific contexts through naming, spatial structuring and mapping activities.

5.1 | Place-making through place-based naming

Place-based naming is perhaps the most obvious way to translate the abstract notion of an IC into a concrete geographical context loaded with specific politico-economic conditions, bio-physical features, socio-cultural meanings and emotional attachments. It not only indicates the absolute location and territoriality of a cluster. By imparting a place imaginary and identity to a cluster, it defines, demarks and accentuates where/who is included or excluded from cluster building. In this sense, naming a cluster after a place is a strategic choice with political implications and can be subject to contestation and modification if the name fails to match up with stakeholders' cluster imaginaries.

To a large extent, the six IDC clusters coincide with the sites for CCUS deployment identified by a feasibility report commissioned by the UK government in 2014 (Ecofys, 2017; Element Energy, 2014), which were reiterated—albeit with a few variations—alongside later consolidations of the UK government's commitment to CCUS (see BEIS, 2018a, 2018b). Likely because of this legacy, NW and SC first appeared in the IDC documents (e.g. Industrial Strategy, 2019) with the names Merseyside and Grangemouth—the same names that were used in previous policy documents—referring to the industrial areas alongside the River Mersey in North West England and Scotland's largest petrochemical complex in its Central Belt area.

While seemingly logical at first sight, these place names were seen as problematic by some stakeholders engaging with these clusters. One informant from SC vividly expressed her frustration when finding that government documents labelled the cluster 'as literally 3,000,000 tons of CO_2 from Grangemouth':

> If I see it again, I will, literally my eyes are gonna pop out of my head and go ballistic, because I'm like, how are we? What is it that we're not saying or not getting through to you guys? [...] and that was the whole purpose of that 'Back the Scottish Cluster' campaign, was to show that this was much bigger than just 3 million tons of CO_2 in Grangemouth, which, by the way, wasn't even part of the Acorn project at that point.
>
> (SC3)

This excerpt echoes the ontological discrepancy between an emitters-based cluster imaginary and a solutions-based one: for the latter, the CO_2 storage and facilities concentrated in North East Scotland and the North Sea are essential components of the cluster. They counter the myth that 'we've got all this CO_2, and it's just magically going to happen that these stores will be there and that they'll absorb it' (ibid.).

Naming a cluster after a perceived 'wrong' place risks under-recognizing the decarbonization efforts occurring outside the suggested territorial coverage. This in turn can generate misleading messages about cluster leadership—with its reputational benefits—as an informant from NW stated:

> We don't like the fact that it's called the Merseyside Cluster because most of the cluster is actually in Cheshire and then government will end up trying to talk to Liverpool City Region officials about it [...] we don't like to see that Manchester, Liverpool leaders because they got mayors get all the limelight and get to be associated that closely with the clusters, when it's our area and our leaders that are more involved.
>
> (NW12)

The statement foregrounds political tensions and power asymmetry between large city regions that often enjoy more media attention and political leverage than small and medium-sized cities and boroughs (Cox & Longlands, 2016; Peacock & Pemberton, 2023). This under-estimation and under-appreciation of cluster leadership is exacerbated when smaller cities or regions are associated with a rural spatial imaginary, as is the case in the county of Cheshire, where several key emitters (e.g. Stanlow refinery) and decarbonization projects are based.

Cluster names thus entail potential demarcation of the periphery and core areas of an IC. For this informant, naming the cluster after the North West of England, which includes Cheshire, Liverpool, and beyond, was a more satisfactory and inclusive option. Even so, the 'North West' cluster name implies an England-centred cluster imaginary that risks neglecting industrial sites and stakeholders key to industrial decarbonization yet based across the border in North Wales, which will be home to the CCUS infrastructure and undersea storage. Mindful of the fact that North Wales partners 'don't see themselves as part of the North West [of England]' (NW2), key actors in this deployment project started to use simply 'HyNet' instead of 'HyNet North West' whenever possible.

These cases suggest the need for a more geographically inclusive place-naming strategy to promote fairness and collaboration in industrial decarbonization, and to avoid contention and a sense of exclusion. In cases where industrial areas are spatially dispersed across a cluster region (e.g. SC and SWIC), an intentionally 'more than local', region/nation-based naming strategy was employed by stakeholders as a means to bond loosely connected industrial actors through a shared place identity. Such a shared identity can potentially contribute to the success of ICs (Rattle & Talyor, 2023) by helping mobilize internal support—including devolved national governments and public—for decarbonization projects.

However, invoking a national identity in naming and marketing a cluster nonetheless risked provoking politically sensitive UK-wide debates regarding the independence of devolved nations.[4] To downplay identity politics that may affect Westminster's attitude (and therefore the likelihood of UK government funding) towards their projects, stakeholders in SC and SWIC attempted to depoliticize their nation-based cluster names by describing them as merely a geographical fact rather than a political claim. In contrast, the cross-national partnership in NW enabled its stakeholders to strategically frame the cluster as 'key to strengthening the Union [of nations in the UK]' (Progressive Energy & MDA, 2021, p. 1) to win over Westminster during the Track-1 CCUS Cluster Sequencing competition, as well as to assure its Wales-based partners of the cluster's potential to 'position Wales as a world leader in hydrogen and carbon capture and storage technologies' (WWU, 2021, para. 11).

In summary, the place-based naming of ICs reveals the political nature of cluster imaginaries in several ways: it associates an IC with a specific place imaginary which entails where and who are accentuated or played down in the cluster imaginaries, thereby fuelling the competition among places within a cluster region. It can also play into multi-scalar identity politics across nations by strategically invoking, downplaying and re-interpreting a place identity for different audiences and political contexts. The contestation over cluster names (and their interpretations) not only adds to the complexity concerning what a cluster means; it also highlights the importance of place sensitivity in IC policymaking and knowledge production in facilitating inclusive cluster building.

5.2 | Place-making through spatial configurations of clusters

A cluster is not only emplaced by its name. It is also emplaced by the deployment of decarbonization technologies and infrastructures in specific geophysical settings. Given the imperative to swiftly decarbonize existing industries, the three case study ICs were largely shaped by existing industrial sites, supply chains, energy/industrial infrastructure (e.g. brownfields), and the geological characteristics of cluster regions (e.g. the presence or absence of nearby underground/undersea saline aquifers). Comparing our three case studies, we found evidence of two predominant cluster spatial configurations, which we term 'pipeline-oriented' or 'polycentric', respectively, following a project-based or site-based rationale (see Table 3).

In the case of NW and SC, which are endowed with undersea CO_2 storage space connected to reusable fossil fuel-based industrial infrastructure (especially gas pipelines and depleted gas fields), the cluster architecture was primarily forged through CCS and hydrogen megaprojects and their connections with key industrial sites.

In NW, the largest GHG emitter and the hydrogen production base of the HyNet project co-locate in Ellesmere Port, giving rise to a relatively concentrated spatial configuration centred on industrial heartlands on the south bank of the River Mersey. The spatial proximity of the industrial and decarbonization activities was framed by industry stakeholders as NW's advantage that can 'substantially lower capital cost and development risk compared to other potential clusters around the UK' (Progressive Energy, 2020, p. 4).

By contrast, SC involves an extended L-shape spatial configuration that stretches from the North Sea and North East Scotland, where the main CCUS and hydrogen facilities are based, to key industrial emitters located along the East Coast and the Central Belt of Scotland. To fully capitalize on the UK's largest CO_2 storage capacity, SC stakeholders highlighted the cluster's economic potential for importing and storing CO_2 from elsewhere in the UK and Europe (e.g. Norway and the Netherlands), as the domestic industrial emissions to be captured and transported with onshore pipelines are comparatively small. Framed as a business opportunity for the UK to position itself as a global decarbonization leader, this vision for international CO_2 shipping gives SC a stronger European connection and identity than other IDC clusters. This is exemplified by the spatial imaginary of its becoming 'the center for a Europe wide carbon storage industry' (NECCUS, NECCUS, n.d., Longer Term Opportunities section). In this sense, SC followed a more relational perspective on emplacement (i.e. the cluster is to be built partly through its relations with elsewhere)—in contrast with the 'insular' emplacement of NW that thus far tended to focus within its cluster region.

SWIC encompasses several dispersed industrial areas specializing in a wide range of manufacturing and heavy industries. This cluster followed 'a "mini-cluster and local-hub" philosophy' (CR Plus, 2020, p. 4). It planned to achieve a regional vision across South Wales through the establishment of several 'clean growth hubs' equipped with localized decarbonization strategies, which can grow into 'mini-clusters' (or 'SuperPlaces') and eventually scale up to all industries

TABLE 3 Cluster-building rationales were identified in the three case studies.

Type	Project-based	Site-based
Rationale	Focused on establishing a megaproject on CCUS and hydrogen to provide a shared solution for industries across locations	Focused on developing localized decarbonization strategies for each key industrial area
Defining condition	CO_2 storage in situ, often accompanied with a gas industry in the region	No feasible CO_2 storage space is available
Predominant spatial configuration	*Pipeline-oriented* • Largely shaped by the pipeline network of one CCUS and hydrogen megaproject • Connected first with key emitters and then potentially expand to smaller and dispersed emitters • Sources and solutions of industrial emissions may or may not co-locate	*Polycentric* • Composed of several sub-clusters that carry out site-based decarbonization plans simultaneously • To be linked through shared infrastructure (e.g. CO_2 shipping, hydrogen backbone) in the future
Outward connections	Depending on the capacity and commercial viability of the CO_2 storage	Strong, esp. for exporting CO_2
Example cluster	NW, SC	SWIC

Note: The spatial structures described here are likely to evolve with the development of the clusters. Additionally, project-based clusters can also be home to various dispersed decarbonization initiatives that may or may not be connected by the pipelines of the megaprojects. Therefore, the two types of cluster structures can be seen as potentially complementary rather than mutually exclusive.

in the region and link with other sectors (e.g. agriculture) through shared infrastructure. As such, SWIC involved a polycentric, more societally embedded cluster configuration, in which 4–5 industrial areas located along the South Wales Coast would simultaneously develop individual place-based solutions while collectively forming a regional-scale decarbonization plan for both industrial and non-industrial sectors. In so doing, it aimed to create not only 'a world leading, truly sustainable industry', but one that 'befitting the societal needs' in the following decades (CR Plus, 2020, p. 4).

Without feasible CO_2 storage, SWIC developed a decarbonization model that emphasizes carbon capture, utilization and shipping. While these 'mini-clusters' are expected to be connected through a major hydrogen pipeline in the future, a CO_2 pipeline to transport captured emissions was not deemed economically effective. Instead, 'a milk round type' activity was preferred (SWIC3), whereby captured carbon will be picked up by small ships and deposited at larger hubs, such as Milford Haven and Port Talbot, and then exported to Norway and other clusters in the UK. Consequently, SWIC stakeholders were more likely to emphasize the need for cross-cluster collaboration than informants from the other two megaproject-based ICs.

In sum, the spatial embeddedness of ICs shaped their cluster-building rationales and led to regional variation in socio-technical configurations (Truffer & Coenen, 2012). The spatial structuring of ICs entailed a reorganization of the relations between key industrial actors and areas inside the region as well as between clusters through managing the flows of industrial emissions. Of central importance are the CCUS and hydrogen infrastructures (e.g. pipelines and shipping), which were selected in accordance with the specific industrial and geographical characteristics of a cluster region and often involved repurposing existing industrial assets. This modification of regional natural, infrastructure and industrial assets (Trippl et al., 2020) suggests the importance of technological relatedness in low-carbon path renewal and diversification (e.g. expanding the gas industry to that of blue hydrogen) as well as in path importation (e.g. attracting a new aviation fuel industry to the region with hydrogen production) (Isaksen, 2015; MacKinnon et al., 2019; Trippl et al., 2020).

Different from the suggestion of the path creation literature, however, the technological relatedness regarding existing gas pipelines, storage and shipping technologies often departed from 'regional fetishism'—an obsession with utilizing resources predominantly inside the region (Binz et al., 2016, p. 173). As in the cases of SC and SWIC, forging linkages to extra-regional industrial sites and exogenous assets, such as shipping CO_2 to external storage spaces, can play a key role in cluster development. The outward connections of new industrial spaces in turn provide opportunities to alter the power relations between places (Bridge et al., 2013) and to fulfil new spatial imaginaries (e.g. transforming Scotland into the heartland of the European CCS industry).

5.3 | Place-making through mapping the clusters

Maps provide a means to visualize the components and spatial configurations of ICs by locating decarbonization infrastructures and projects in and beyond a specific region referred by the cluster name. They can strengthen certain cluster ontology (e.g. where it is, what it comprises and can deliver, see Section 4) at different stages of its formation, while simultaneously facing challenges regarding their accuracy from viewers holding different cluster imaginaries. Thus, examining stakeholders' perceptions of cluster maps helps illustrate the contested, relational and dynamic spatiality of these ICs. Moreover, cluster maps are not mere the representation of some cluster imaginaries. They also materialize and co-define these imaginaries through the performance of (re)producing, adjusting and circulating these maps on official websites, in mainstream and social media and at business conferences, along with other cluster-building activities (e.g. the construction of decarbonization infrastructure).

Various cluster maps were produced and utilized by policy-makers and cluster stakeholders for different audiences and purposes. They enabled cluster leads to communicate cluster visions and their socio-spatial impacts to broader stakeholders, and to showcase the booming initiatives and rich industrial assets in the cluster region to attract investment. Although the contents of these maps vary in accordance with the intended audiences and the messages to be conveyed, they usually involve key industrial and decarbonization activities, facilities and initiatives in the identified region. In all three case studies, no consensus existed among cluster stakeholders regarding the geographical scope, centre and future expansion of these clusters, although some general tendencies can be identified from the diverse responses (see Table 4).

As with the imagining of clusters, the multiplicity in describing the spatiality of a cluster stems from the informants' personal experiences with cluster building and is case-specific. For instance, in NW, whose naming is relatively vague compared with the other two cases (i.e. can be interpreted as the North West of England or the North West of the UK), answers regarding its geographical scope tended to diverge more than the other two cases, while less divergence existed regarding its centre thanks to the co-location of its largest emitter and the major hydrogen production base in Ellesmere Port. Informants from SWIC and SC were more likely to emphasize overseas connections than NW, due to the reliance on CO_2 shipping in their decarbonization plans.

TABLE 4 Diverse views on the spatial characteristics of ICs elicited by discussion of cluster maps.

Dimensions	Responses	Examples
Geographical scope	The administrative boundaries of a region/nation	'That is the conventional definition, government definition of the North West [of England].' (NW11)
	The key industrial areas within a region/nation	'Southern part of North West of England and North East Wales' (NW7)
	Unsure, but bigger than the geographical coverage of the megaproject	'it's quite difficult, because I don't work too much on the cluster plan stuff. But I would say, I mean, definitely the cluster is wider and bigger than HyNet, and it's all more infilled.' (NW2)
	No given boundaries; the cluster extends wherever the decarbonization infrastructure goes	'I don't particularly think of any particular borders [...] as long as they're close enough for the pipelines to get there and work. I don't think political borders need to get in the way.' (NW8)
Centre/core area(s)	The biggest emission site(s), or the base of key decarbonization projects, or the combination of them	'Where the current core is, is in the Port Talbot, because that's where the biggest amount of CO_2 has been being generated. But the future core, in my view, yeah, almost the starting point, and where the lifeblood is, is going to be Milford Haven. Because [...] the Celtic Sea will be pivotal [...] in developing the green energy sources that will power those industrial clusters.' (SWIC13)
	Depending on the topics	'it's clearly around the sort of Cheshire and Warrington area [...] that is the area that has the highest CO_2 emissions [...] if you looked at decarbonization of transport, I think Greater Manchester should be the focus [...] But when you look at things like decarbonization of energy, you've clearly got Lancashire and Cumbria' (NW3).
	The geographical centre of the cluster which happens to be a key industrial area	'we're trying to make our headquarters in Port Talbot area, because it's about an hour's drive each way' (SWIC2)
	All key industrial areas	'you've got Milford, you've got Port Talbot, Cardiff, and Newport. And that is historically where the industries have been located, where the ports are as well.' (SWIC5)
	Where the stakeholder's organization is based	'Milford Haven, obviously [laugh]. I've got a bias there. But no, I think... there is no core centre because it's all interdependent on one another.' (SWIC11)
	No place is more important than the others because of their interdependence	
Future expansion	Expand with the decarbonization infrastructure and activities into other areas within or/and outside the cluster region. But some informants distinguished the expansion of a deployment project from that of a region-based cluster	'obviously expanding to cover... what's happening elsewhere in Europe, whether it's pipelines or whether it's that... ship you've got' (SC6) 'I think that's a way of expanding the Acorn project [i.e. importing CO_2 from elsewhere], but not really the Scottish cluster. Because it's, they're not within Scotland for a start [...] It's an expanding the use of the Scottish, the Scottish store, that is beneficial to the cluster in terms of lowering cost overall, because there be more tonnes going into the store, but it's not really expanding the cluster.' (SC4)
	Connections (rather than expansion) with other clusters via CO_2 shipping or the interface of infrastructure	'So geographically, I'm not sure the North West cluster can expand, because if it does expand, it kind of goes into some of the other clusters. I think the way it can expand is in its interface with the other clusters, and how we can look at complementary infrastructure that can sit between those clusters.' (NW3)
	No expansion as it's already big: focuses instead on internal connection with industries that has not been incorporated to the cluster building (esp. SMEs in dispersed areas)	'I don't think it should. I think it's plenty big enough.' (SWIC9) 'It's really that... engagement, then, of the sort of smaller medium sized industries, and how do they sensibly and economically catch a carbon, and utilize hydrogen, and the decision making.' (SWIC3)
	Oversea connections mostly foreseen through import/export of CO_2, H_2, and decarbonization technologies and skills; but some informants question the need or the priority of these connections	'At this stage, no. I think we have enough production in the UK to address our own concerns. And... I would see that there is a potential future for import and export of hydrogen, but we are not technologically there yet in terms of the pipeline requirements to deliver that.' (NW5)

Overall, three common features can be discerned from these cluster maps. First, the maps are often 'deliberately vague in terms of [their] placement' (SWIC1), functioning more like a heuristic illustration of what is (or will be) taking place to decarbonize regional industries (e.g. Figure 2). This ambiguity, according to some informants involving in the mapping activities, was strategically employed, partly in response to uncertainty at the initial stage ['when we've got more certainty, we can add more detail to the map' (NW2)] and partly to avoid potential controversies arising from identifying too specifically the sites of proposed decarbonization infrastructures. This indicates that mapping an IC, which was usually conducted by the cluster leads with the help of communication agencies, is part of cluster branding activities, involving strategic selection of what is to be included or excluded to create a concise, attractive and uncontroversial image of the cluster for targeted audiences.

Second, political/administrative boundaries on these maps are often deliberately downplayed (Figure 3). Besides the aforementioned project uncertainty, for some informants, this feature illustrated that a cluster map was 'not a political map', but 'an industrial map and decarbonization map' (NW9) or 'a wider economic opportunity map' (NW5). This underplay of IC politics by cluster stakeholders was particularly notable in the NW case—the only IDC cluster that crosses the border between two UK countries (England and Wales). It illustrates the inclination of industry stakeholders to transcend bureaucracy and political risks associated with traversing administrative boundaries, which added complexity and could be a source of frustration for project development. As an informant expressed,

> We're very clear that conversations can't stop at the border [between England and Wales]. Makes it slightly more complicated because it's a different regulatory regime and government sort of support regime on the other side of the border. But from an industrial perspective, those borders shouldn't matter or can't matter, because, you know, they're just administrative boundaries.
>
> (NW9)

The excerpt highlights discrepancy between the boundaries of governments and those of decarbonization projects that involve multiple and multi-scalar political spaces (Binz et al., 2020). Following geo-historical and economic logics more than political ones, the cluster building process necessitated the (re)grouping of existing industries, economic organizations and local authorities, each of which entailed different territorialities. For instance, SWIC connected actors in separate industrial areas in South Wales who had 'never worked really in clusters' (SWIC2), while forging partnerships with stakeholders in South West England through projects like the Western Gateway, a pan-regional partnership of local authorities and trade unions to form collective actions towards net zero. Meanwhile, industries in North Wales joined

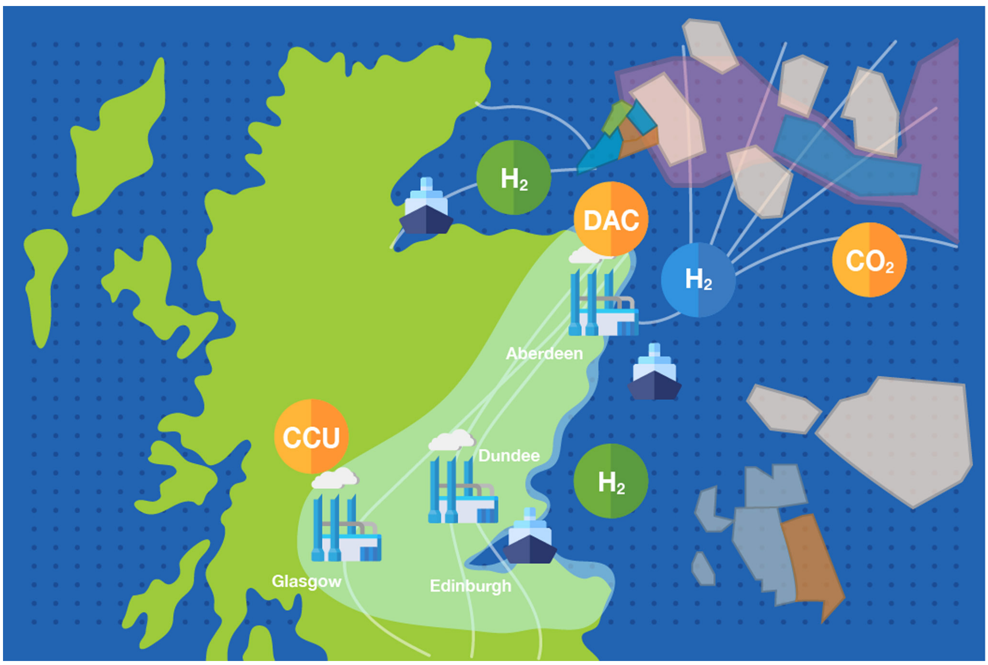

FIGURE 2 An illustration of industrial decarbonization plan for Scotland, showing the L-shape spatial configuration of the cluster and its outward connections. DAC refers to direct air capture facilities and CCU stands for carbon capture and utilization. *Source*: SNZR.

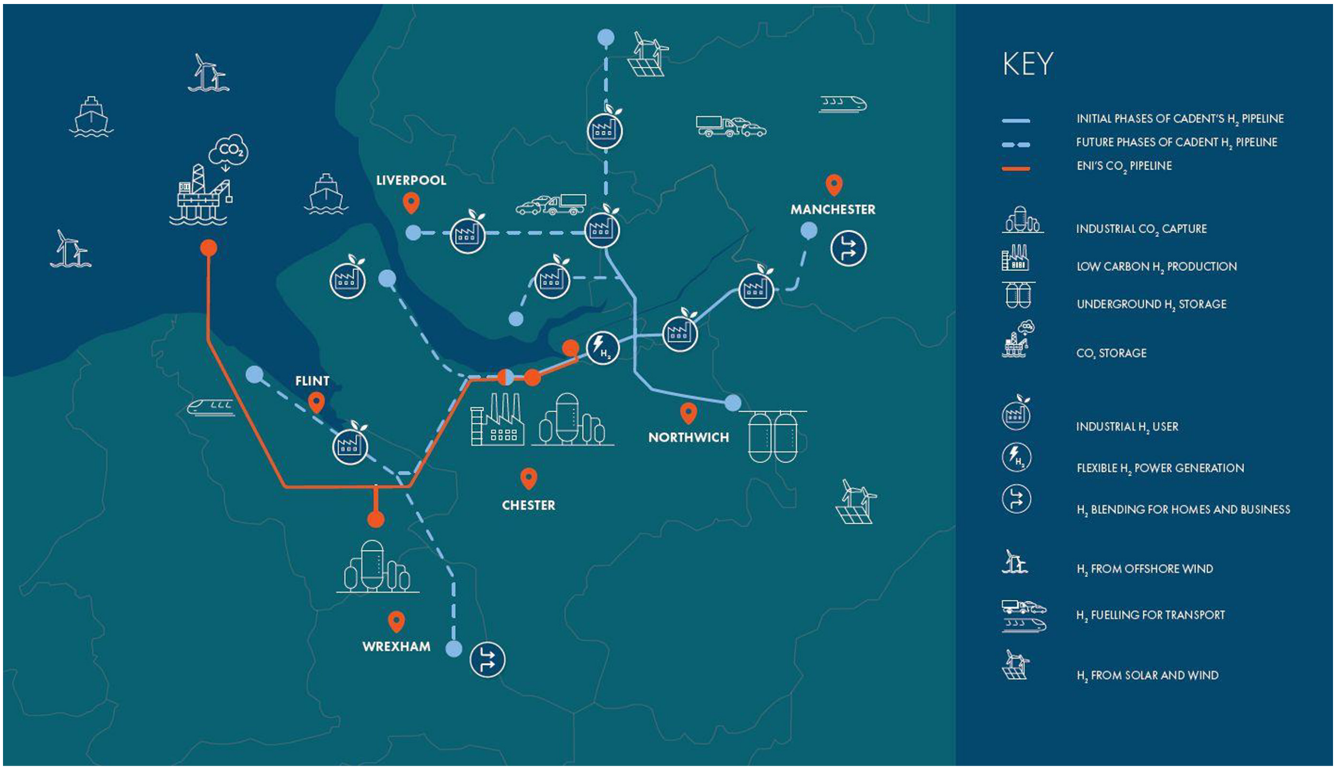

FIGURE 3 A map of the HyNet project in NW. *Source*: Progressive Energy.

with Cheshire West in the North West of England, with which it has historical connections and forms 'arguably a functioning economic area in its own right' (NW9). A national-scale 'Welsh Cluster' (similar to the Scottish Cluster) was not deemed likely by informants, given geographical barriers (e.g. remote uplands) and disconnected infrastructures (e.g. gas networks) between South and North Wales. Even if the geo-infrastructural divide could be partially addressed through political intervention (i.e. the establishment of a formal entity endorsed by the Welsh Government to oversee Wales-wide industrial decarbonization), they are expected to remain in two separate clusters working together to achieve national policy goals.

A third feature of the maps is that they require updating or replacement as clusters develop. Deviating from serving as 'tools for the naturalizations of specific propositions' which then 'become incontestable and foreclose alternative energy futures' (Castán Broto & Baker, 2018, p. 5), these cluster maps are subject to constant change and contestation. For instance, the symbol for offshore CO_2 storage in the Celtic Sea was removed from an initial map of SWIC partly because of the lack of feasibility of this option, and partly because of objections received from a local community located near the marked landfall of its CO_2 pipeline (Figure 4). This testifies to the need for a process-oriented perspective on the spatiality of low-carbon transitions (Bridge & Gailing, 2020).

The deliberate ambiguity in maps about project locations, their transcendence of political and administrative boundaries, and the temporality of cluster map-making illustrate the limitations of employing a notion of absolute space to imagine emergent industrial clusters. Instead, it is necessary to visualize relational spaces that are constantly evolving with changing elements and unfixed boundaries (Castán Broto & Baker, 2018). As Murphy (2015, p. 76) argued when proposing a place-making perspective on transition studies, context 'is fundamentally a relational rather than a territorial phenomenon, constituted through connections, flows, locations, and scales that often transcend the boundaries of nation-states, cities, and/or other commonly deployed geographical units'. One challenge to contextualize cluster imaginaries with maps thus lies in communicating the 'relations' between the decarbonization projects and a wide range of audiences, as one informant pondered: 'None of them [maps] are good enough for me. I think this is too abstract for people [...] it talks about infrastructure rather than "what does it mean for me"' (SWIC13). Considering the plural cluster imaginaries at play, it is perhaps unsurprising that no single map in each case was agreed upon by all informants as an accurate visual representation of the cluster.

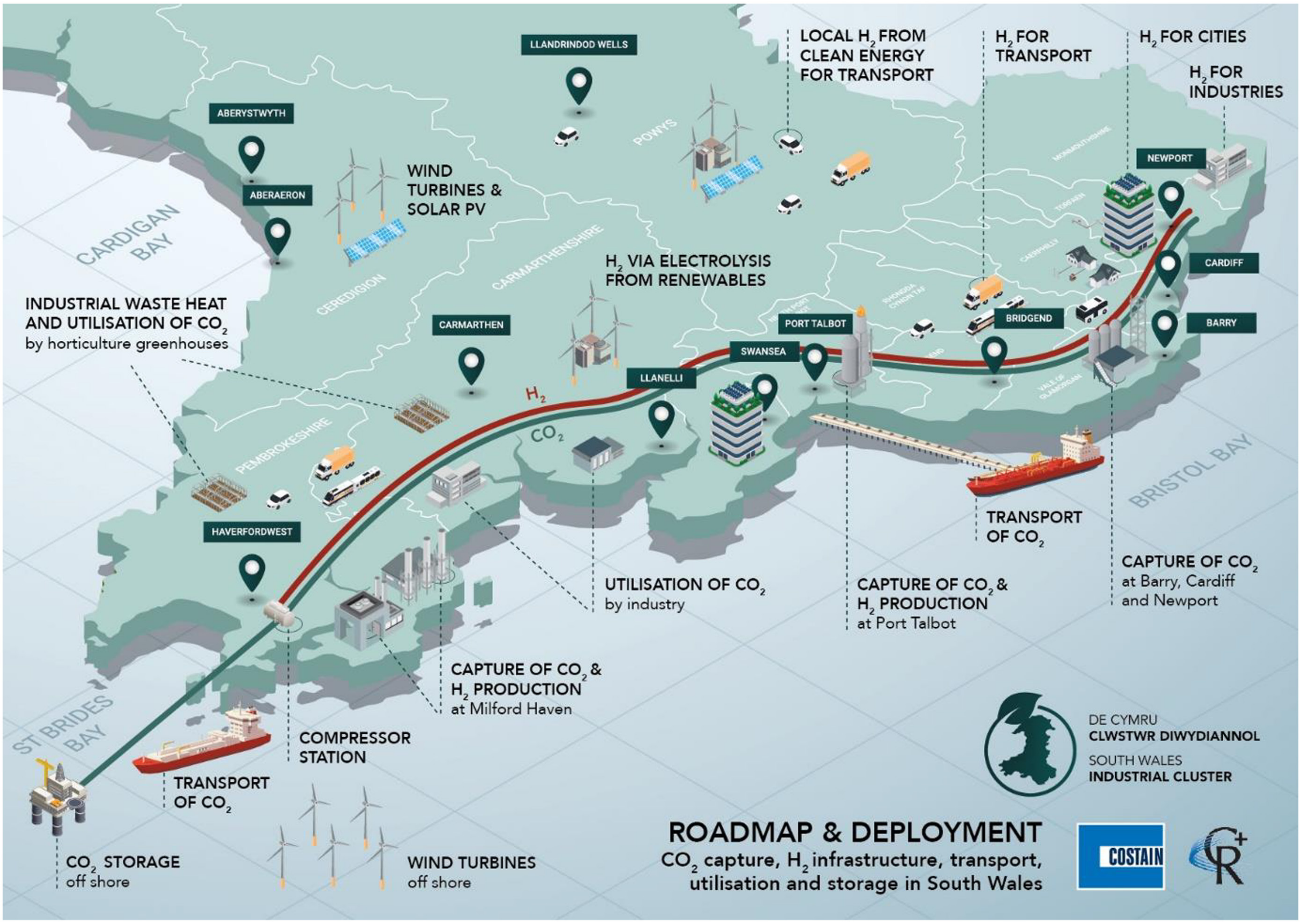

FIGURE 4 An initial map of SWIC envisioning a future for the cluster that was later replaced by new plans. *Source*: Costain.

6 | DISCUSSION

These findings on the current imagining and discursive emplacement of ICs have numerous theoretical and policy implications for a genuine 'place-based' approach for industrial decarbonization. In this section, we first elaborate on how stakeholders' strategic emphasis on ICs' spatial embeddedness—which underlies the spatial configurations of ICs—invites a more sophisticated understanding of 'spatial lock-in' and 'path dependence' in energy and evolutionary economic geographies, while revealing a selective and instrumental understanding of place in current cluster imaginaries. Second, we discuss how the naming and mapping of ICs, specifically dynamic, contested boundary-setting, highlights issues of fairness in and beyond cluster building, and foregrounds the need for a network perspective on scale for inclusive industrial decarbonization. Third, we reflect on the technocentric ontology of the cluster approach that dominates industrial decarbonization policies and discourses in the UK and worldwide (Devine-Wright, 2022; Eadson et al., 2023; Rattle & Talyor, 2023). We will show how its tendency to support top-down, 'one-size-fits-all' technological solutions fail to respond to the complexities in IC's ontology, naming, spatial configuration, and mapping described above. As a consequence, we conclude by calling for a more place-sensitive approach to IC planning and deployment.

6.1 | Lessons from ICs' spatial configurations: strengths and weaknesses of social embeddedness in cluster discourses

Our findings on ICs' spatial configurations suggest a need for a more sophisticated understanding of the role of spatial embeddedness in low-carbon transitions. While recognizing the importance of contextual conditions in enabling a new path, the innovative projects' reliance on existing infrastructures and cultural-institutional arrangements in a place is often referred to 'path dependence' in energy and evolutional economic geographies—a concept that stresses 'continuity' rather than change, and therefore contradicts the notion of transitions in the long-term (Bridge et al., 2013; Martin, 2010; Martin & Sunley, 2006). However, spatial embeddedness—including the sunk cost of capital investment in existing built environments—was celebrated as a strength for low-carbon industrial transitions by stakeholders in all three cases. As a promotional article for SC argued (Pearson, 2021):

> Instead of building expensive new pipelines, along with organizing new planning consents, training a new workforce in gas handling, and building new ports and processing facilities, with all the associated environmental impact, all of which are being considered in the UK and the world, everything we need is already here, in spades.

Such 'spatial lock-in' (Bridge et al., 2013, p. 339) was strategically reframed as a selling point to attract investors and government support: First, it was claimed to allow ICs to deploy urgently needed decarbonization technologies in a more low-risk, socio-ecologically acceptable and swifter manner, assuming re-inhabiting spaces that were already 'industrialized' would engender less landscape change and public objection. Second, it was used to demonstrate the cluster stakeholders' commitment to the regions and their recognition of 'the importance of a really sound understanding of local context, with local needs and early identification of the right stakeholders' (All-Energy, 2021). Third, it reproduced an industrial place identity that necessitated net zero industrial transitions (instead of decarbonization through de-industrialization) by invoking the regions' industrial legacy and local workers' 'real massive sense of pride, of being part of something, of being part of that revolution, industrial revolution and all this' (SC3). Last, it aligned with the 'just transitions' agenda, as explicitly suggested in the case of SC (see SNZR, 2020 for instance), by repurposing existing workforce and preparing them for jobs expected to be created through the transition process.

However, reference to the place in these discourses tended to be selective and instrumental, which can in turn compromise the claimed 'merits' of ICs' spatial embeddedness in supporting a fair and rapid transformation of industrial regions. For instance, place-based elements were mentioned only when being conducive to present attractive images of ICs, as exemplified by the cluster maps. Negative impacts of industrial development (e.g. pollutions and social inequalities) were largely omitted when proud industrial identities and the potential to 'level up' declining industrial areas were highlighted. Moreover, these claimed 'benefits' of spatial embeddedness could be used to legitimize those industries' preferences for CCUS and blue hydrogen production projects over more radical measures, thereby raising suspicion of greenwashing from environmental groups (Gough & Mander, 2022), while 'locking out' alternative decarbonization options (Bridge et al., 2013; Stephenson & Allwood, 2023) and different place visions held by non-industrial actors (Devine-Wright, 2022). They may also re-place fossil fuel-based industries that sacrifice the well-being of nearby communities (Cowell, 2020).

Nevertheless, these 'benefits' of spatial embeddedness have helped form coalitions of investors and (often multinational) companies, drawing attention to the economic, social and cultural ties they have with the places of their making, if in a selective and limited way. This emphasis on spatial embeddedness may function merely as a rhetorical strategy to serve industry interests in some cases. But it can also provide an opportunity for local authorities, local communities, and civil society groups to advocate and pressure industries in the region to commit to a form of place-making consistent with sustainable regional and local development. These strengths and limitations of spatial embeddedness suggest the intricate entanglements of path dependency and creation (e.g. consolidating while challenging fossil fuel-based structures and interests) and the mixed nature of spatial lock-in (e.g. simultaneously accelerating and constraining innovation) in the context of low-carbon industrial transitions.

6.2 | Lessons from naming and mapping ICs: dynamic boundary-setting, inclusivity and rescaling ICs

Our findings on cluster naming and mapping reveal that the boundary setting of ICs is constantly evolving and subject to contestation. This raises important questions concerning which places are prioritized or marginalized in the making of net zero industrial spaces. These findings also indicate the prominent role of dynamic boundary-setting in (re)scaling ICs for the delivery of inclusive and holistic industrial decarbonization. We suggest this network topology of scale deserves more research attention in exploring the multi-scalar dynamics in low-carbon transitions, apart from the translation of institutional rationales across levels raised in recent discussion (e.g. Miörner & Binz, 2021).

UK IDC cluster regions are not equally sized, ranging from a built-up area around a river estuary (e.g. Teesside) to a devolved nation (e.g. SC, in expectation). As our findings suggest, the actual geographical coverage/scale of a cluster is subject to the dialectics between policy preferences, existing industrial and geographical conditions of a place, the expansion of decarbonization infrastructures and the manageability of networking. Thus, it is context driven, constantly evolving and contested even if government policies define it as 'regional'.

This raises challenges for policy-makers and cluster stakeholders in defining what places, actors and industrial activities are included and prioritized, and where/who/what are left out and denied access to government funding and decarbonization infrastructures, as implied by the disagreements over cluster names and maps. Several informants noted the pitfalls of policy preferences placed on big energy users and emitters, which risked neglecting the needs of smaller industries dispersed within or beyond a cluster region, whose contribution to the local economy and GHG emissions are considerable (see also Rattle et al., 2023).[5] This demonstrates the interrelation between place and justice concerns in various forms, such as fair allocation of resources and support, (under-)recognition of a place's (e.g. Cheshire, St. Fergus) leadership in the cluster development, and the asymmetrical power relations between regional actors in cluster building. Without appropriate policy attention to these place-based justice issues, the 'levelling up' effects of net zero ICs can be compromised, as the creation of cores and peripheries in the emerging new industrial spaces may consolidate—rather than redress—existing regional inequalities (Skjølsvold & Coenen, 2021).

As a response, many informants envisaged a scale-up of clusters through extending infrastructure boundaries and linking places. In this sense, accelerating UK-wide industrial decarbonization requires not only the alignment of projects and policies across levels (Gough & Mander, 2022); it also requires the dynamic (re)scaling of clusters by expanding or combining their geographical coverage for creating a collective, national approach to mitigating GHG emissions. UKRI, the initiator of the IDC programme, has started working on a 'UK-wide cluster plan' that would draw lessons from individual IDC clusters to facilitate decarbonization efforts in and beyond these cluster regions. In the longer term, these clusters are expected to be connected via the expansion of decarbonization infrastructures, such as CO_2 shipping and the deployment of 'Project Union', a Britain-wide hydrogen pipeline network project instigated by National Grid. This in turn will emplace an IC in the broader geographies of CO_2 and hydrogen supply chains across the UK and beyond, whereby its boundaries are likely to become less clear. As such, while a regional scope may be necessary for clustering stakeholders and decarbonization initiatives in the early phases of cluster development, one possible or ideal UK net zero pathway is that these region-based clusters 'would probably start to dissolve in the future' (NW4), when they are merged into or constitute a broader UK cluster plan similar to the configuration of 'mini-clusters' in SWIC. In this sense, ICs resonate with Bridge's (2018, p. 15) call for 'a much more fluid understanding' of new energy spaces.

The imagining of rescaling ICs through dynamic boundary-setting suggests the relevance of 'a network topology' and a relational perspective on scale (Coenen & Truffer, 2012; Coenen et al., 2012; Truffer & Coenen, 2012, p. 11) in understanding net zero industrial spaces. As GHG emissions 'won't stop flowing at the border' (NW3), such a 'horizontal' (re)scaling strategy (in contrast to scalar hierarchy, such as local and national) is important for low-carbon transitions. Indeed, all three case study ICs involve the co-existence of multi-scalar actions and plans in many localities that contemporaneously form part of 'a UK mission' and 'a global mission' of climate mitigation (SWIC1). This rescaling strategy through networking enables '[n]urturing polycentrism for rapid climate and energy transitions' (Skjølsvold & Coenen, 2021, p. 5). It also allows dispersing 'decision making capabilities and change agency' to enable context-informed decarbonization efforts across places at the same time (ibid), which Skjølsvold and Coenen (2021) argue is vital for accelerating low-carbon transitions without sacrificing inclusivity.

6.3 | Policy implications: critiquing a technocentric ontology in net zero policy

These insights regarding spatial embeddedness and (re)scaling offer critical reflections on net zero policy in the UK and other countries. Thus far, policy and broader discourses on industrial decarbonization and cluster building worldwide have been dominantly shaped by a techno-managerial perspective (Eadson et al., 2023; Rattle & Talyor, 2023). We argue that, despite policy claims of being 'place-based' (e.g. aiming to create 'SuperPlaces' in struggling industrial heartlands—see Devine-Wright, 2022), a competitive cluster approach that rests on technology deployment is deficient in responding to the diverse, fluid and contested nature of a net zero industrial space reflected by complexities in cluster ontology, configuration, naming and mapping.

Our evidence suggests that the tendency in policy discourses to view industrial decarbonization from a technocentric perspective weakens the ability of national policy-makers to respond to the spatial dynamics and regional variations of ICs. The CCUS Cluster Sequencing Track-1 programme is a case in point. While it is reasonable to set policy priorities for various decarbonization solutions (e.g. pipeline-based CCUS targeting domestic emissions) given limited resources and time, this funding scheme nonetheless uncritically prioritized a certain imagining of ICs. In so doing, it overlooked the geographical specificities that co-define the spatial configuration and decarbonization strategies of an IC as well as the borderless, multi-scalar characteristics of industrial decarbonization.

Compounded with the competition between ICs, this CCS and pipeline-focused cluster ontology added to the concerns of some informants over fairness and inclusivity in resource allocation across regions and decarbonization solutions. As a result, the Track-1 status was awarded to clusters that fit neatly into this policy cluster imaginary, such as NW. By contrast, clusters whose spatial structures diverge from this cluster imaginary, such as SWIC, found themselves in a vulnerable position in the funding competition, which in turn disadvantaged them in the 'globalized place wars' (Boland et al., 2020, p. 793) over various forms of investment, resources, and talents for industrial transitions. As a SWIC informant stated:

> We've got all of those entities, 40 plus industrial partners, all or most headquartered overseas, all looking at future investment plans, all thinking, 'well hang on, UK government has just said that they're not interested in the South Wales cluster'.
>
> (SWIC1)

Given the dynamic spatiality of international capital and multinational companies, the negative political signal from the Track 1 result, along with the loss (or delay) of funding and political support that comes with it, could make these clusters less appealing to potential investors and the parent companies of their industrial partners, who might move their resources to other places. For these cluster stakeholders, this policy bias 'poses a real threat' to the development of their decarbonization projects and their commitment to the cluster regions (i.e. the claimed 'benefits' of IC's spatial embeddedness). To tackle this policy challenge, they emphasized the need for a 'collective approach' ['to ensure that the whole of the UK moves at a reasonable pace' (ibid.)], in which SWIC's non-pipeline-based decarbonization strategies could provide solutions for other similar clusters and regions, and hence should not be left behind in government funding. This case suggests the positive potential of a 'horizontal' rescaling strategy (i.e. linking SWIC to other clusters and the UK-wide cluster plan) in addressing the a-spatial tendency of a technocentric policy.

The CCS-based cluster ontology also risks downplaying alternative, more context-appropriate strategies (e.g. CO_2 shipping and utilization) that are needed for unpacking these ICs' full decarbonization potential and for decarbonizing industries in the dispersed sites (Rattle et al., 2023). It led to the exclusion of the largest industrial emitter in the UK (in SWIC) and the largest CO_2 storage space (in SC) from the Track-1 funding. By emphasizing domestic carbon capture, it also fell short in facilitating potential collaboration between clusters in need of CO_2 storage spaces (e.g. SWIC) and those 'designed to receive early CO_2 imports from other parts of UK' (ETZ, 2021, p. 1) (e.g. SC), which helps scale up the decarbonization efforts across borders to meet UK's climate targets.

For these reasons, we argue that a genuine 'place-based' IC policy requires going beyond a techno-managerial perspective that conceives place mainly as 'a container' of decarbonization technologies (see also Eadson et al., 2023 for a similar criticism). Instead, a place-sensitive approach needs to take seriously the geographical connotations, conditions and consequences of cluster development in a holistic manner. It needs to be sufficiently attentive to the complexity of industry-place relations, issues of inclusivity in cluster building and rescaling and the diversity of cluster imaginaries emerging from specific regional contexts. As the UK's example shows, a technocentric competitive approach for industrial decarbonization inevitability creates winners and losers between places (Devine-Wright, 2022; Rattle & Talyor, 2023; Skjølsvold & Coenen, 2021), which could contradict the policy goals of rebalancing regional equalities and fulfilling these regions' decarbonization potentials. Consequently, to establish an effective 'UK-wide cluster plan' and to achieve the UK's net zero socio-technical/spatial imaginary requires a place-sensitive policy mindset from the start—one that is capable of drawing inspiration from plural cluster imaginaries/structures/strategies embedding in diverse geographical contexts and attending to the fluid, connected and contested boundaries of ICs. The same lessons can be applied to other countries in order to re-imagine industrial decarbonization using a more place-sensitive approach.

7 | CONCLUSION

This paper addressed a lack of geographically informed empirical research on emergent net zero industrial spaces. To do so, it employed a place-based research agenda to investigate for the first time the spatiality of net zero ICs created by the industrial decarbonization agenda, with a focus on the imagining and emplacement of these spaces in policy and industry discourses. Using evidence drawn from three UK ICs, it showed that the notion of cluster was not self-evident, but diverse, sometimes contested and varied across cases and policy contexts. These diverse cluster imaginaries involve different geographical connotations and interpretations that have political consequences as well as the potential for mobilizing (extra-)regional support to obtain resources and funding.

These findings advance the understanding of spatial embeddedness and scale in the geographies of low-carbon transitions. First, ICs' reliance on existing industrial assets to form their net zero spatial configurations and solutions, though increasing the risk of path dependency, reflects some degree of recognition by industrial actors of their economic, social and cultural ties to these places. This may help increase their accountability for (re)making these industrial places. Second, ICs' fluid boundaries highlight the necessity to attend to ways that industrial actors, sites, and activities can be excluded from cluster-building processes. A rescaling strategy through dynamic boundary-setting emphasizes the value of a network topology of scale in conceptualizing and tackling spatial inequalities in low-carbon industrial transitions and the borderless nature of climate mitigation. These lessons inform just transitions by recognizing regional differences in strengths and needs, fair resource allocation across places, and inclusive participation in decarbonization processes. However, the technocentric ontology of the UK net zero policy has failed to fully recognize regional variations and to address the dynamic spatiality of ICs, as evidenced by our findings on the complexities of cluster ontology, configuration, naming and mapping. Therefore, we argue that a place-sensitive net zero policy mindset is vital for fulfilling ICs and the UK's decarbonization potential in a manner that is both fair and grounded in local needs and strengths.

Directions for future research can include: First, the competition between different cluster imaginaries and existing senses of place can be an interesting topic for exploration. From the perspectives of GOST and Science and Technology studies, a special focus is required on the place-making politics in which visions for industrial decarbonization appropriate, reshape or collide with place visions held by local communities and non-industrial actors (Gough & Mander, 2022). Second, with the deployment of technologies leading to the materialization of cluster imaginaries, researchers can be attentive to the consequences of specific projects (e.g. emerging CCUS and hydrogen supply chains that connect up diverse industries), including changes in industrial agglomeration, landscape, people-place relations and spatial inequalities. From a regional path creation perspective (Trippl et al., 2020), this will require a close examination of the effects, mechanisms, and mobilization of actors and assets in enabling low-carbon regional development through green industrial restructuring. From a political economy perspective (Bridge & Gailing, 2020; Huber, 2016), researchers could investigate the embedding of net zero industrial transitions in the spatiality of capitalism, examining socio-ecological conflicts resulting from changing material flows of energy and resources (Labussière et al., 2018). Together, these explorations can build on the findings of this research to further develop the emerging geographies of industrial decarbonization.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge support from the UKRI Industrial Strategy Challenge Fund (ISCF) as part of the Industrial Decarbonisation Research and Innovation Centre (IDRIC) award number: EP/V027050/1.

DATA AVAILABILITY STATEMENT

Cluster and policy documents that support the findings of this study are mostly available in the public domain (for weblinks of these data, please see the references). Data generated from interviews with stakeholders are confidential and thus not sharable.

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ENDNOTES

[1] Despite the long-standing influence of Michael Porter's 'cluster theory' on the UK's regional policymaking (Swords, 2013), the notion of ICs referred in the UK's industrial decarbonization policies differs significantly from the typical, though contested, definitions of 'clusters' in these studies (Martin & Sunley, 2003). Unlike the 'geographic concentrations of interconnected companies and institutions in a particular field' (Porter, 1998, p. 78), such as the IT cluster in Silicon Valley, the net zero ICs are set to involve companies across diverse sectors, which may or may not be interlinked through existing supply chains, and can be dispersed across the cluster region. Moreover, these ICs are identified by their significance in industrial emissions besides their economic contribution. Instead of geographical

proximity and economic connections, their members are bonded by the common objective to create a regional low-carbon economy conducive to their future development. In this sense, these ICs align more with an industrial ecology model (Leigh & Li, 2015; Lowe & Evans, 1995), but with a pre-occupation with abating carbon emissions from fossil fuel combustion: they often involve redesigning the industrial ecosystem in ways that improve resource and energy efficiency and industrial symbiosis, as well as the creation of a close-loop for carbon emissions with the deployment of decarbonization technologies (e.g. fuel switching to hydrogen) and infrastructures (e.g. CCUS pipelines).

[2] BEIS was replaced by the Department of Energy Security and Net Zero (DESNZ) in February 2023.

[3] UKRI is a BEIS-sponsored non-departmental public body launched in 2018 that funds research and development initiatives.

[4] This happened against the broader political backdrop of a referendum in 2014 for Scottish independence from the UK, which is still a key policy goal of the Scottish devolved government.

[5] Industries dispersed outside 25 km of potential CO_2 injection points at major ports count for 47.2% industrial emissions in the UK (HMG, 2021a).

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How to cite this article: Lai, H.-L. & Devine-Wright, P. (2024) Imagining and emplacing net zero industrial clusters: A critical analysis of stakeholder discourses. *Geo: Geography and Environment*, 11, e00139. Available from: https://doi.org/10.1002/geo2.139

APPENDIX 1

LIST OF MAPS USED IN INTERVIEWS

IC	No.	Type	Description	Sources
NW	1	HyNet Project + Cluster Plan	Core HyNet Area and associated Cadent Gas distribution network	Cadent & Progressive Energy (2017) 'The Liverpool-Manchester Hydrogen Cluster', p. 3 Progressive Energy & Cadent (2022) 'HyNet the Road to Net Zero', p. 3
	2	HyNet Project	Indicative representation of the HyNet Project	Cadent & Progressive Energy (2018) 'HyNet North West: From Vision to Reality', p. 4 & 12 Cadent (2018) 'HyNet North West: Delivering Clean Growth', p. 6 JM, SNCL & Progressive Energy (2020) 'HyNet Low Carbon Hydrogen Plant: Phase 1 report for BEIS' HyNet NW (2020) 'HyNet North West: Unlocking Net Zero for the UK', p. 2 NZNW (2021) 'Net Zero North West Economic Investment Prospectus', p. 42
	3	HyNet Project	HyNet Cluster	NENW website- News JM, Kent & Progressive Energy (2021) 'HyNet Low Carbon Hydrogen Plant: Phase 2 report for BEIS', p. 13 Vertex Hydrogen website, 'About HyNet' HyNet NW (2022) 'Preliminary Environmental Information Report Volume I: Non-Technical Summary', p. 4
	4	HyNet Project	HyNet Project Concept	HyNet NW website-About HyNet CO_2 pipelines public consultation brochure Progressive Energy & Cadent (2022) 'HyNet-the Road to Net Zero', p. 1 NZNW (2022) 'North West Cluster Plan: Interim Findings', p. 8
	5	HyNet Project	Facilitators and opportunities for project extension	Cadent & Progressive Energy (2018) 'HyNet North West: From Vision to Reality', p. 19
SWIC	1	Cluster plan	Four preliminary mini-clusters in South Wales	CR Plus (2020) 'South Wales Industrial Cluster: A Plan for Clean Growth', p. 6
	2	Cluster plan + Deployment	Initial map for SWIC roadmap and deployment (with offshore CO_2 storage)	SWIC website- News release CR Plus (2020) 'South Wales Industrial Cluster: A Plan for Clean Growth', p. 4
	3	Cluster plan + Deployment	Map for SWIC roadmap and deployment	SWIC website
	4	Deployment	Map for SWIC deployment	SWIC website SWIC (2022) 'A Year in the Life of South Wales', p. 4

IC	No.	Type	Description	Sources
SC	1	Cluster plan	Geographic scope of the core Scottish Cluster	SNZR (2020) 'Phase 1 Summary Report', p. 2
	2	Cluster plan	Core area and key decarbonization projects	SNZR website- About
	3	Acorn Project	Acorn Hydrogen	Acorn Project website, 'About Acorn' webpage
	4	Acorn Project	Acorn Hydrogen location at St. Fergus Gas Terminal	Acorn Project website—About, News Element Energy (2020) 'D06-Hydrogen in Scotland; the role of Acorn Hydrogen in Enabling UK Net Zero' PBD (2020) 'Expression of Interest Form' for hydrogen demand Slide for the Scotland Hydrogen Webinar PBD (2021) 'Acorn Project: Project Summary HSC-2 Report', p. 6
	5	Cluster plan	Longer-term opportunity for SC beyond 2030	NECCUS website-A Vision

Note: All the websites were accessed on 06/06/2022.

APPENDIX 2

INTERVIEWEES FROM THREE CASES

	Total	Cluster leads	Other industry stakeholders	Government actors		Trade organizations	Academia	Other key actors
				Local	National			
NW	12	2	3	2	–	3	1	1
SWIC	13	2	5	1	1	1	1	2
SC	6	2	2	1	–	–	1	–

Note: 'Cluster leads' refer to the organizations that led the applications for the roadmaps/cluster plans and the deployment projects of the IDC cluster programme. These include two energy consulting firms (NW and SWIC), one decarbonization development business (SC), one industrial infrastructure and property company (NW), one construction and infrastructure company (SWIC), and one public-private alliance (SC). 'Other key actors' denote organizations outside of the aforementioned categories that play an important role in the formation and development of these ICs, such as a cross-nation organization (NW), a port authority, and a formal non-governmental entity created for the governance of an IC (SWIC).

APPENDIX 3

TWO FUNDING PROGRAMMES THAT CONSTITUTE THE UK'S COMPETITIVE CLUSTER APPROACH

Programme	Industrial decarbonization challenge (IDC)	CCUS cluster sequencing
Duration	2019–2024	2021–
Policy foundation	2017 *Industry Strategy* 2021 *The Grand Challenge* policy paper • The Industrial Clusters Mission of 'Clean Growth' Challenge	2020 *Ten-Point Plan*
Initiator	UKRI	BEIS

Programme	Industrial decarbonization challenge (IDC)	CCUS cluster sequencing
Funding sources	£170 million Industrial Strategy Challenge Fund (ISCF) + £261 million match funding from industry	£1 billion CCS Infrastructure Fund
Programme design	2 phases of competition regarding 2 dimensions • Phase 1 (2019–2020): Roadmaps + deployment projects • Phase 2 (2021–2024): Cluster plans + deployment projects	2 tracks of competition • Track 1 (2 phases): CCUS clusters + associated carbon capture projects • Track 2 (2023)
Definition of clusters	Region-based • Areas with a number of industrial sites that serve as key hubs of local activity and an important part of the UK economy (Industrial Strategy, 2019)	Technology-based • Comprising a CO_2 transport and storage network and an associated first phase of at least two CO_2 capture projects (BEIS, 2021)
Aims	• Green growth for the UK and cluster regions • The world's first net zero industrial cluster by 2040 • At least one low-carbon industrial cluster by 2030 (increased to 4 in 2021)	• To boost the infrastructure deployment for carbon dioxide transportation, and storage • 2 CCUS clusters by the mid-2020s • 4 CCUS clusters by 2030
Focus	• Region-based decarbonization actions as economic boosters • Key industrial emitters + key decarbonization projects (not limited to CCUS and hydrogen)	• Pipeline-based CCUS deployment • Domestic emissions
Winners	6 IDC clusters • North West, South Wales, Scotland, Teesside, Humber, Black Countries	2 Track-1 clusters • HyNet Cluster (North West) & the East Coast Cluster (Teesside + Humber) • The Scottish Cluster as the reserve cluster 2 Track-2 clusters • Acorn (Scottish Cluster) & Viking T&S systems (Humber)

Note: (1) Carbon capture for the purpose of usage was not included in the CCUS funding scheme at this stage (BEIS, 2021, p. 39–40). (2) T&S systems refer to (CO_2) transport and storage systems.