Cheaper by the Cluster? The Politics of Infrastructure Collaboration for Industrial Decarbonization*

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April 17, 2026
Word Count: 12,029

Abstract

Under what conditions do firms cooperate rather than compete when providing public goods? I study this in the context of industrial decarbonization in the U.K. Conceptualizing common infrastructure technologies as club goods suggests a non-linear relationship between cooperation and group size. Given spatial externalities inherent to these technologies, group size is shaped by the density of firm production sites. Within the firm, the decision to cooperate or compete varies with production site concentration: firms are more likely to pursue cooperative strategies at production sites that are highly concentrated. With original production site and firm data from the U.K., I present three sets of results using a policy shift to study trends in firm behavior. First, I demonstrate that firms with highly concentrated production sites are more likely to cooperate. Second, these firms, increasingly reference decarbonization and climate change in mandatory disclosures. Third, interviews with these firms provide insights on the robustness and variation in the depth of cooperation and project development.

*This draft benefited from helpful feedback from several individuals. I thank Sarah Bush, Didac Queralt, and Melissa Pavlik in particular. Interview research approved by Yale IRB # 2000035376.

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Introduction

In early 2023, five cement and lime companies in northern England announced the formation of a business association with the goal of jointly decarbonizing production across their production sites. The Peak Cluster, over the following decade, will build a carbon capture and storage infrastructure network (CCS) to eliminate industrial emissions by capturing emissions at the source before transporting these gases via a pipeline for permanent storage in a depleted oil well in the Irish Sea.[1] While the pace of emissions reduction in one of the most carbon-intensive industries is striking; what is puzzling is that this joint endeavor emerged from a group of *direct* competitors. This effort parallels state-led initiatives to develop decarbonization "clusters" by the British government, yet the Peak Cluster has been largely a private endeavor: It received no funding from government until two years after its formation. Upon completion, the project will eliminate roughly 3 million tons of CO_2 per year or just under 1% of all British emissions. The firms in the Peak Cluster are investing substantial resources to privately supply a public good: greenhouse gas reductions. Existing explanations of firm preferences and behavior towards public good provision in the climate realm stress the importance of comparative advantage (Kennard, 2020), supply chains (Cory, Lerner and Osgood, 2021), or the risk of regulation (Baehr, Bare and Heddesheimer, 2026; Sautner et al., 2023) from a perspective which views individual firms as competing with industry peers (Melitz, 2003).

At face value, this competition-driven logic appears largely absent in the case of the Peak Cluster, and more broadly among other decarbonization associations in the British context. Following the announcement of the Industrial Decarbonization Challenge in 2019, the British government has prioritized a cooperative framework to industrial decarboniza-

[1] In the context section below, I provide a more thorough introduction to CCS and other deep decarbonization technologies available to emission intensive industry.

tion through large-scale infrastructure projects such as CCS as well as hydrogen networks, complementing a longer-standing regulatory approach based on carbon prices.[2] Cooperatives have emerged and some have been funded by the government in diverse regions of the country, for example Manchester, Humber, and South Wales. Government outlays in the initial funding call were a meager £210 million, compared with the substantial £20 billion budget allocation for price supports upon operation (i.e., closer to 2030). While government can sweeten the deal through green industrial policy, not all of the initially targeted areas have successfully developed. In Manchester, we observe a large-scale CCS network breaking ground in 2025 and further south the Peak Cluster has continued development with little support, but in Southampton and South Wales progress is stalled despite public funding. Clearly, public support *alone* is not a solution, hence this chapter asks the following two questions: First, why do firms, at times, cooperate to (semi)-privately supply public goods to address climate change? And, second, what explains the varying levels of progress or success in ultimately providing these emissions reductions?

Faced with regulatory pressure to eliminate emissions, this chapter develops a production site based explanation of firm public good provision via cooperation. I develop this argument in three steps. First, given that the decision to provide environmental goods is a cooperation problem (Hardin, 1968; Ostrom, 1990; Barrett, 2003; Kennard and Schnakenberg, 2023), I conceptualize these deep decarbonization technologies as *intermediate club goods* due to their excludable benefits, semi-rivalrous properties and critical mass thresholds for development. This conceptualization provides intuition on the emergence of cooperation which is non-linear in its relationship to group size (Buchanan, 1965; Olson, 1965; Cornes and Sandler, 1996). Second, I argue group size, in the present context, is shaped by

[2] Examples of similar policies outside the U.K. context include: the U.S. Department of Energy Hydrogen Hubs Program, the EU Important Project of Common European Interests on Hydrogen, the French Industrial Decarbonization Zones Program, among others.

the geographic concentration of industry given spatial externalities inherent to these deep decarbonization technologies. Hence, I expect that the concentration of production sites facilitates the existence of and participation in a decarbonization association across the economy and at the firm-level respectively. I conceive of three ideal types of firms based on their production site geography to clarify the importance of focusing on production sites to understand firm behavior vis-à-vis decarbonization cooperation. First, firms, in which all production sites are isolated, *never* cooperate. Second, at the other extreme, firms, in which all production sites are co-located to other emission intensive production sites, *always* cooperate. Finally, firms, in which some production sites are co-located and others are isolated, *mix* their strategy. Put simply, I expect the latter two types of firms to participate in these decarbonization cooperatives.

Due to financial and human capital constraints which make these deep decarbonization innovations infeasible for even the largest firms, cooperation provides a means of pooling resources and provides firms with a strong green comparative advantage upon completion. Put simply, as one sustainability director remarked, the firm's logic for participation is "cooperation now, compete later."[3] Lowered investment costs and alongside club productivity benefits suggest firm preferences towards decarbonization should be more optimistic following cooperation. State assistance can further incentivize both directly and indirectly cooperation among geographically proximate production sites, reinforcing a geographic cleavage between and within industrial firms with respect to climate policy. This assistance can be thought of creating market conditions which enable a low-carbon value chain from emitters of myriad sectors to gas transporters and storage operators.

I assess these first two components of the argument with original data of the population of carbon-regulated as well as cooperating firms between 2014 and 2023 in the United

[3]Interview 2. 7/2023.

Kingdom. This provides me with both cross-sectional data on where cooperation is taking place and which firms are cooperating. Using the announcement of the Industrial Decarbonization Challenge (IDC) as a paradigm shift in the climate policy space, I combine production site geographic and emissions data to assess whether firms with highly concentrated sites are more likely to participate, both in the presence and absence of state targeting in a set of event study designs. By concentration, I mean a production site's proximity to other emission intensive firm's production sites, not to other sites of the same firm. To assess whether cooperation is meaningful, that is it shapes firm interests with respect to climate change and decarbonization, I leverage a decade's worth of mandated disclosures and measure whether directors mention climate change and decarbonization in their annual strategic reports in a second event study. To contextualize the text analysis, as a final step, I assess whether climate change and decarbonization are presented differently in these disclosures by firms that cooperated versus their regulated peers in a word embedding regression framework (Rodriguez, Spirling and Stewart, 2023).

Cross-sectionally, I find evidence consistent with a positive relationship between group-size, measured as the local concentration of industry, and cooperation throughout the U.K. This relationship holds omitting areas originally funded by the IDC. At the firm-level, I make two findings. First, I find that firms with highly concentrated production sites are more likely to cooperate in decarbonization clusters compared to their more isolated peers after 2019. This result is likewise robust to the omission of firms participating in decarbonization associations targeted by the IDC. Substantively, a one standard deviation increase in the maximum production site concentration (16 additional emission intensive production sites) is associated with a 25 percentage point increase in the likelihood of a regulated firm participating. Second, I find that cooperating firms are increasingly likely to mention climate change and in particular decarbonization following 2019 compared to firms facing climate regulation but not cooperating. These firms are 16 and 20 percentage points more likely to mention climate change and decarbonization in their strategic reports. The results from the word-embedding analysis suggest cooperating firms see more benefits from decarbonization and climate change and increasingly associate the former with an infrastructure-based approach. Together, these results provide consistent evidence of production site concentration levels shaping firm behavior, both in the presence and absence of direct state assistance.

To begin to understand variation in the development and success of decarbonization cooperation, I inductively develop the third component of my argument from roughly 30 semi-structured interviews, site visits and informal conversations with engineers, sustainability directors, and local government officials during several months of fieldwork in the U.K. These data likewise allow me to validate assumptions guiding the above argument. With respect to variation in the extent of cooperation, these qualitative data provide a more nuanced explanation of how geographic concentration facilitates cooperation as well as other factors contributing to decarbonization progress. First, beyond reducing investment costs, concentration, by increasing the potential group size, improves the resiliency of project development. It better ensures a minimum viable project with sufficient emissions for economies of scale, but also reduces the likelihood of unilateral defection by any one participant from making the collaborative effort nonviable. Second, given these fertile conditions for deep decarbonization, success is more likely in the presence of what I call cooperative entrepreneurs: actors with longer time horizons that facilitate cooperation among participants who might otherwise not participate or defect given that socialization rates are typically low prior to participation. Both characteristics do not hinge on state support.

This research speaks to several enduring questions in the study of politics. First, on the firm provision of public goods, I provide novel theory and evidence of a complementarity between short-term cooperative dynamics and medium- to longer-term competitive dynamics shaping whether firms engage in costly investments to reduce emissions by conceptualizing decarbonization technologies as intermediate club goods (Buchanan, 1965; Cornes and Sandler, 1996). This extends existing approaches based on short-term competition driving firm preferences and behavior towards regulatory standards (Kennard, 2020; Perlman, 2020; Gulotty, 2022). Second, prominent arguments for climate clubs typically focus on the international level (e.g., Keohane and Victor (2011); Nordhaus (2015); Falkner, Nasiritousi and Reischl (2022)), I demonstrate how similar solutions to the cooperative game exist in the domestic political economy in the absence of anarchy given that firms are mobile across national territories in a globalized economy. Finally, prominent developments in political economy research emphasize the importance of a firm's position with respect to its sector as driving firm behavior in terms of trade, climate, as well as lobbying and special interest politics more generally (Kennard, 2020; Baehr, Bare and Heddesheimer, 2026; Cory, Lerner and Osgood, 2021; Kim, 2017; Osgood, 2018; Hanegraaff and Poletti, 2021; Gulotty, 2022; Hanegraaff, Poletti and Aizenberg, 2023; Brutger, 2024). Rather than considering firms as unitary actors, I motivate an explanation for firm decarbonization behavior based in its components, namely production sites. Given the concentration and expansion of large, multi-site firms in domestic and international politics, relaxing this unity assumption provides a novel source of variation to explain firm behavior.

Concentration, Club Goods, and Deep Decarbonization

To ground the intuition behind private firms cooperating to provide public goods rather than pursuing a production strategy that maximizes profits and therefore carbon emissions in a non-cooperative fashion, I build on insights from two literatures. First, I incorporate insights from the extensive literature on collective action, and more specifically related to club goods. This work highlights rivalry, excludable benefits and that a minimum threshold of actors is needed to facilitate the benefits of cooperation, meaning that the relationship between group size and cooperation is non-monotonic. Second, I consider recent research that examines the conditions under which private actors, namely firms, provide public goods. This political economy research demonstrates that when short-term profit motives align firms will provide public goods in the pursuit of market share gains.

Synthesizing these two strands of research, I conceptualize infrastructure projects for deep decarbonization as *intermediate club goods* which facilitate the private provision of public goods. In the presence of high fixed costs, exclusive benefits, and operating congestion, this leads me to expect a weakly positive relationship between group size and the development of these projects. I microfound this aggregate expectation at the firm-level by presenting a typology of firms with respect to the distribution and concentration of a given firms production sites. This clarifies which firms are more likely to cooperate, but also at which production sites this cooperation takes place. These productivity-enhancing benefits from cooperation suggest that firms interests related to climate change and decarbonization should shift. I then consider the role of the state in this cooperation, primarily through its use of green industrial policy as a market creating device.

Cooperation, Clubs, and Public Good Provision

When considering whether to abate or continue polluting, actors decision-making is typically considered to take the form of a prisoners dilemma (Barrett, 2003). Incentives to free-ride result in a situation that is detrimental to the environmental commons; this result, is, moreover, increasingly difficult to escape as the number of players grows (Barrett, 2003). This tragedy of the commons (Hardin, 1968) relies on the good resulting from cooperation being purely public, however. When a pure public good is not in question, the logic of collective action does not necessarily apply.

Scholars of public goods provision typically classify goods along a continuum between perfectly private and public goods with other types of goods featuring either excludable benefits or rivalrous usage sitting between these two extrema (Samuelson, 1954; Tiebout, 1956; Olson, 1965; Chamberlin, 1974; Ostrom, 1990; Cornes and Sandler, 1996). Club goods feature both of these characteristics. When the benefits from a given good are partially excludable, collective action problems attenuate as free-riding benefits for non-participants are less present. When usage of the good is rivalrous, meaning that a given actors usage of it limits anothers, problems of congestion arise: as more and more actors take part in the good there are diminishing returns to group size (Buchanan, 1965; Cornes and Sandler, 1996). This suggests a non-monotonic relationship between group size and cooperation in the presence of these club goods. The extent to which benefits are increasing with smaller group sizes depends on the presence of fixed costs of cooperation needed to reach a critical mass of participants (Oliver, Maxwell and Teixeira, 1985). Absent sufficient resources, potential participants may not be able to provide the club good until a certain resource threshold is met.

The Firm Provision of Public Goods

Recent explanations of the private provision of public goods demonstrate that firms can, when profit motives align, behave in such a way as to unilaterally support or provide collective goods such as greater regulatory stringency, minimum standards, and monitoring or enforcement of legal standards (Kennard, 2020; Perlman, 2020; Gulotty, 2022; Brutger, 2024). For instance, Kennard (2020) emphasizes how firms supporting greater climate regulation stand to benefit vis-à-vis their intra-industry competitors; increased regulation leading to lower emissions, a public good, comes with greater market share, a private good, for those firms possessing a green comparative advantage. Similarly, Gulotty (2022) describes how large firms, better able to pay the fixed costs of higher standards, have lobbied for increasingly stringent product safety codes at the expense of their smaller competitors. Here, barriers to entry reduce competition and drive market share gains by these large firms. In both cases, private benefits facilitate the provision of public goods (i.e., less pollution or higher safety standards, respectively).

Firms, in existing research, act unilaterally to provide these public goods with the underlying mechanism driving behavior being increased profits and ultimately market share. These profit incentives are, moreover, typically defined in the short term. Quickly realized private benefits can ultimately facilitate the provision of public goods. Building on above, I will argue that firms cooperate to provide public goods when club goods provide them increased profits and ultimately market share. Cooperation, in the presence of club goods, provides a complementary means by which private actors provide public goods.

The Argument

Incorporating insights from above, I develop my argument in three parts. First, I conceptualize deep decarbonization infrastructure projects as *intermediate club goods*. The spatial externalities inherent in these projects alongside their club good status lead me to expect them to be more common in areas with a higher number of industrial firms. Second, I provide a typology of firms based on the distribution of their production sites vis-à-vis other firms production sites to connect this aggregate expectation to firm characteristics. Lastly, I incorporate public actors, by considering how the states role through the provision of green industrial policy shapes firm cooperation.

Net zero requires industrial firms to make fundamental adjustments to their production process. For those sectors with process emissions that cannot be eliminated via electrification,[4] deep decarbonization options are typically limited to capturing emissions at the smokestack or replacing natural gas fuel stocks with carbon-free or green hydrogenboth options are cheapest via network-based infrastructure projects. While prohibitively costly from the perspective of a single industrial firm, these infrastructure projects are more feasible via a consortium approach in which firms collaborate to provide the necessary resources for their development. I argue these infrastructure projects are better conceptualized as intermediate club goods given that they feature excludable benefits, rivalry in their use, and require a critical mass of participants to develop. I unpack each in turn to motivate this conceptualization.

First, benefits from these infrastructure projects are excludable given that firms must link up to the network. Absent a pipeline connection, firms cannot partake in the benefits of net-zero production that come with these technologies. This excludability reduces concerns about free-riding among potential participants. Under an increasingly stringent carbon pricing system as is the case in many advanced economies, this net zero production provides firms with a strong green productivity advantage over their competitors.

Second, usage is non-rivalrous to an extent. Pipeline diameters, gas pressurizing stations and terminals can only handle a given flow rate before additional infrastructure needs to be built. Put differently, these infrastructure projects suffer from congestion in a similar fashion to highways or telecommunications networks.[5] While excess capacity could be designed into initial construction, there is no incentive for cooperating firms to shoulder these costs for future entrants. These latter actors would be, in effect, free-riding on the

[4] Process emissions are those which result from the production process, such as chemical reactions. Sectors with process emissions include steel, cement, and petrochemicals among others.

[5] These congestion costs are most likely to be present in terms of pressurizing stations and pipelines. Terminals in the United Kingdom, for instance, have substantial redundancy, with flow rates at the various stations often under 50%. See https://data.nationalgas.com/gas-system-status.

over-supply of infrastructure by early movers.

Lastly, these infrastructure projects require a critical mass of emissions to spread the fixed costs of investment across several firms production sites. Commercial risks preclude even the largest industrial firms from undertaking these investments unilaterally. Absent a sufficient number of firms, not only the financial, but also the epistemic resources to develop different parts of the infrastructure project are unlikely to be met. For example, industrial firms needing to capture emissions at the smokestack are complementary to gas transporters and storage operators within the infrastructure project. The former is unlikely to possess the resources and know-how to operate the latter components and vice versa.

Table 1: Firm Considerations regarding Decarbonization Infrastructure Projects

<table>
<tr><td>“Collaboration is really important for getting this pipeline built, if it was just one emitter, I don’t think it would happen.” (Sustainability Director, Industrial Firm, I4.)</td><td>“Emitters don’t have a project without a [carbon] store and the [carbon] store doesn’t have a project without the emitters, so we are developing together.” (Project Manager, Oil Firm, I9.)</td></tr>
<tr><td>“It [concentration] enables a sharing of cost and risk, but also people with skills and this industrial heritage.” (Project Manager, Engineering Firm, I11.)</td><td>“We needed CO_2 sequestration for gas storage...we wanted a high concentration of industrial emitters...If you know a little bit about the energy sector intellectually, it’s not that difficult to put those building blocks together.” (Project Manager, Engineering Firm, I12.)</td></tr>
<tr><td colspan="2">“This presented an opportunity for us, literally our plant in the UK is in the right place at the right time so this [cooperation] is a must do. This was an opportunity for us to decarbonize. There is a lot of commercial sense in it. I’m currently sitting at another production site, we are developing completely different decarbonization strategies to suit the geography for this particular factory. My view and the company’s view on the approach taken for decarbonization is that it needs to be customized for each geographic location. For our other factory, we have a completely different strategy.” (Sustainability Engineer, Industrial Firm, I8.)</td></tr>
</table>

Taken together, the presence of all three characteristics suggests these infrastructure projects, as club goods, require several firms to be feasible; the spatial externalities inherent to these networks means that areas of dense industrial activity are more likely to have them. Both hydrogen and CCS networks operate via pipelines, meaning that commercial costs are decreasing with the concentration of production sites. With increasingly clustered production, there is simply less pipe and construction needed to decarbonize the same quantity of emissions. Moreover, adjacent firms can share gas pressurizing stations rather than needing to develop their own. In Table 1, I provide interview responses substantiating aspects of this conceptualization as well as evidence of firms adopting varied decarbonization strategies by production sites. That is, firms adopt heterogeneous decarbonization strategies at the production site level. For example, one sustainability director remarked how they were cooperating on a CCS project at one concentrated site, but considering other unilateral reductions at a more isolated site.[6] Another sustainability engineer working at a manufacturing firm was more explicit remarking that his "view and the company's view on the approach taken for decarbonization is that it needs to be customized for each geographic location."[7] This discussion leads to the first hypothesis:

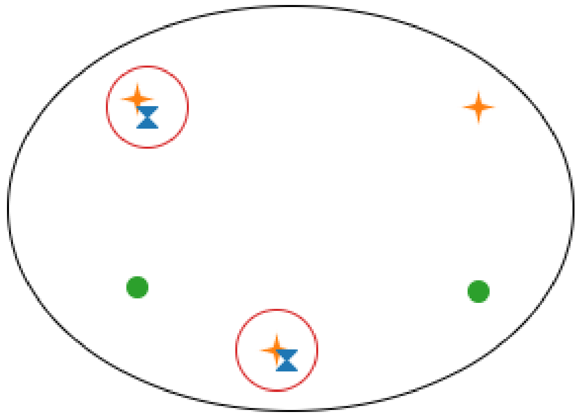
H1. Areas with a greater concentration of industrial production sites are more likely to have decarbonization cooperatives than less concentrated areas.

In Figure 1, I present an illustration a stylized economy to introduce the production site-based logic of firm cooperative behavior. The different shapes denote different firms with each shape being a production site. The rings encompassing multiple production sites denote a cooperation pact to develop an infrastructure project. Ignoring the reason this cooperation comes about, the illustration permits a consideration of three ideal types of

[6] Interview 2. 7/2023.
[7] Interview 8. 2/2025.

firms based on their production site decarbonization strategy.

Figure 1: Three Ideal Types of Firms



The three types of firms are always cooperators, sometimes cooperators, and never cooperators. The blue hourglass firm always cooperates as both of its production sites are co-located with the orange star firm, allowing them to pool resources and develop projects. In contrast, the green circle firm never cooperates. Its production sites are isolated from the other production sites and therefore cannot join these projects. Lastly, the orange star firm is a sometime cooperator: when co-located with the blue hourglass firms production sites it cooperates, but it does not do so at its more isolated production site.

Figure 1 presents a highly simplified rendering of an economy, but it clarifies the locus of decision-making for industrial firms: the production site. When considering whether to cooperate or not, firms are not unitary actors, but vary their behavior based on production site characteristics. From the production site perspective, firms similar to the blue hourglass or orange star firm are more likely to cooperate than the green circle firm. That is, emission intensive firms with production sites co-located to other emission intensive firms production sites are more likely to cooperate in the development of these infrastructure projects. I emphasize emission intensity as this is the key discriminating feature of the production site: whether it has ample emissions. Co-located emission intensive production sites need not be in the same sector to facilitate project development. Production sites without ample emissions, however, are of no help in reaching the critical mass. In practice, most firms will resemble the orange star firm: a sometime cooperator depending on the concentration characteristics of its production sites. For instance, as noted above, the firms at which both sustainability directors I spoke with work would resemble the orange star archetype: their firm cooperates at some production sites, but not others. With respect to firms, I expect:

H2. Firms with production sites in highly concentrated production areas are more likely to cooperate in a decarbonization association than firms with more isolated production sites.

Given the substantial potential productivity gains from these deep decarbonization innovations, cooperation is likely to shift the interests of participating firms in particular related to climate change and decarbonization. Aware of the risks of sunk costs towards the development of these projects, cooperating firms are more concerned with securing an infrastructure-based industrial decarbonization trajectory. Prior to even breaking ground, for example, firms must invest substantial resources in preliminary engineering, consultations, and regulatory processes, a non-trivial portion of total investment.[8] Whereas existing research emphasizes how realized green capital drives firm interest expression (Kennard, 2020), I expect that cooperation and this unrealized green productivity gain is sufficient to shift interest given the sunk costs and transformational productivity gains of these projects. Firms may lobby, build support among stakeholders, among other activities to demonstrate

[8] The front-end costs of these projects was a consistent theme among interviewees. One described the trajectory of costs in the development process as increasing by an order of magnitude at each stage. Interview 12. 3/2025.

this interest, therefore I expect:

H3. Following cooperation, cooperating firms demonstrate a greater interest in climate change and decarbonization than non-cooperating firms.

Table 2: Firm Considerations on the Role of the State

"The market isn't ready to move, you can't do this without government intervention for anyone [firm] that trades globally." (**Engineer, Industrial Firm, I21.**)	"The fundamental challenge is the cost of carbon is not embedded fully in our economies... The reality is the [carbon] price does not reflect the true social impact nor is it very predictable. It's level and volatility don't drive investment." (**Project Manager, Engineering Firm, I7.**)
"The government is taking a systems architect role for this...is a highly, highly regulated industry...There are about eight regulators we need to satisfy." (**Project Manager, Oil Firm, I9.**)	"The cost of decarbonization is more than the cost of doing nothing at the moment. If you are a cement plant, it obviously costs more to capture emissions than to not. So clearly there is a role for government through subsidies today because decarbonization is a public good. Politically an ever increasing carbon price isn't achievable... if the carbon price was 150 to 200 pounds we wouldn't be having this conversation about CCS subsidies." (**Project Manager, Engineering Firm, I12.**)

Thus far, I have ignored the role of the state and considered purely private interactions. Yet, given the cost of these projects, it is unlikely firms will pursue them absent strong and stable market signals (Besley and Persson, 2023). Given market failures of pollution externalities, state intervention, broadly, is a necessary condition of this argument, but the state need not *directly* intervene on behalf of*each* firm. Governments, via green industrial policies, can step in and further reduce the commercial risks faced by firms seeking to decarbonize through seed grants, loans, as well as price supports during operation, among other financial incentives (Rodrik, 2014; Allan and Nahm, 2024). These interventions serve to create a market for infrastructure projects with state assistance either directly spurring cooperation or indirectly catalyzing it among firms who missed out and fear falling behind. In the present context, I assume that governments in advanced economies have an interest in reducing emissions while maintaining industrial employment as they target a mid-century net zero.[9] This dual motive makes supporting cooperative projects highly attractive as the pooled private resources can reduce the total expenditure of the state at times. Table 2 presents interview responses that attest to the role of the state as a market creator for these infrastructure projects; the necessity of state intervention to address market failures was commonplace in both sustainability engineers and directors answers. For example, one project manager elaborated the rationale behind state intervention saying, "The fundamental challenge is the cost of carbon is not embedded fully in our economies... It's [the carbon price] level and volatility don't drive investment."[10] This project manager is aware not only of the market failure related to negative externalities arising from industrial production, but they also note that the carbon tax, an efficient option for addressing this market failure, is currently insufficient, hence targeted subsidies may be more appropriate. The heavily regulated nature of oil and gas development in the North Sea was another common motivation for a strong coordinating role of government, beyond merely providing subsidies.[11] In what follows, I provide additional context on the role of the British state in industrial decarbonization and policy development over the past few decades. I likewise give an overview on CCS and hydrogen.

[9] In the British context, the presence of a legally binding net-zero target is in line with this assumption.

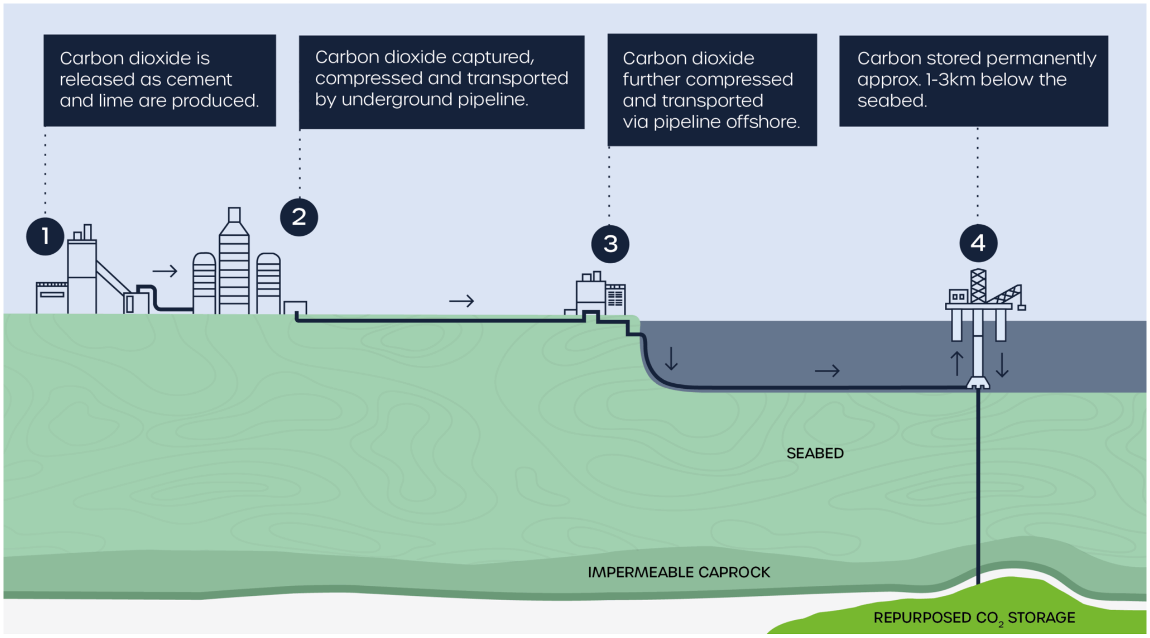
[10] Interview 7. 2/2025.

[11] Interview 9. 2/2025.

In this section, I briefly overview public interventions in the U.K. to spur industrial decarbonization. I first provide a brief technical primer on the two main technologies: (1) CCS & (2) hydrogen. This discussion leads to me consider the Industrial Decarbonization Challenge as a breakpoint in British industrial assistance. One geared more towards a cooperative rather than competitive relationship between firms. Further details can be found in Appendix A.

CCS and hydrogen represent two deep decarbonization technologies, meaning they fundamentally transform the production process by reducing emissions effectively to zero. CCS does this by capturing emissions and storing them permanently underground, typically in saline aquifers or depleted oil or natural gas wells. In practice, this process includes different actors at three stages in the "low-carbon" value chain: (1) emissions capture at the industrial production site, (2) the transportation of these emissions, and (3) their permanent storage. Figure 2 provides a stylized example of this process from the Peak Cluster. Hydrogen, for decarbonization purposes, is considered a substitute for natural gas, typically in heating applications in the production of ammonia, steel and petrochemical materials. "Low carbon" hydrogen can either be produced from natural gas with CCS or using electrolyzers and a renewable energy source to split hydrogen and oxygen atoms in water. Current hydrogen production production is characterized by splitting natural gas to isolate hydrogen with CO_2 released to the atmosphere.

Figure 2: Carbon Capture and Storage Process



In the British context, early attempts at using industrial policy to create a CCS or hydrogen sector from scratch focused on large scale pilot projects. These demonstration attempts were concentrated in the power generation sector, had a single firm attempt to operate the entire three-step value chain described above, with large outlays by the state to fund project development. These early stage projects failed to launch, leading the National Audit Office to conclude, in a highly influential 2017 report, that these early stage policies were failures.[12] This failure was attributed to an inability of individual firms to handle all three parts of the value chain.[13]

Acknowledging these value chain concerns, the government launched a renewed effort to push industry towards net zero with the Industrial Decarbonization Challenge (IDC) in

[12]Informal conversation with bureaucrats in the Department of Energy Security and Net Zero (DESNZ) as well as private sector interviewees emphasized the importance of this document in shifting the government's approach to funding CCS.

[13]The full report can be found here: https://www.nao.org.uk/wp-content/uploads/2017/01/Carbon-Capture-and-Storage-the-second-competition-for-government-support.pdf.

2019. The IDC adopted a cluster-based approach to decarbonization in which firms, alongside local government and research institutions, were provided with seed grants to develop place-based decarbonization plans. The IDC identified the six largest emissions concentrations and framed it as a competition for further funding rounds and price supports.[14] Broadly, the IDC marks a shift from an industrial policy characterized by demonstration projects towards a territorial-based form of business collaboration.

I use the IDC as a break point in the empirical design below. While a result of both private influence efforts as well as lessons learned from the audit report described above, I use it as a way of assessing how firm interests and behavior have changed over time. This policy lets me assess the aggregate, but also firm-level hypotheses motivated above. In the aggregate, given that some associations existed informally prior to the IDC's announcement,[15] it lets me assess the means by which states can shape private interests. With respect to individual firms, given that not all firms in identified areas participate and some form associations elsewhere, I can assess the micro-level efficacy of policy both directly and indirectly. I provide more details on how I assess my argument in what follows.

Data and Design

To test the observable implications of the theory above, I collected firm-level data on participation and communication in the United Kingdom, between 2014 and 2023. These quantitative data serve as a complement to the qualitative data from fieldwork that let me further refine the theory above, generating insights about the depth and intensity of cooperation. As a first cut, I assess the relationship between industrial concentration, that is at the grid-cell, and cooperation likelihood. This lets me assess the general implications of the argument. To do this, I rely on original data on decarbonization associations in

[14] The six areas are North West, Humber, South Wales, Black Country, Scotland, and Teeside.

[15] The HyNet Project, for instance, has been in the works since 2015 according to several interviews.

the United Kingdom and the participating firms as of 2023. Using this cooperation data, I then link firms to regulatory and disclosure data with national business identifiers and assess the firm-level hypotheses above. That is, I use this universe of participating firms and complement it with all firms regulated by the UK Emissions Trading System (ETS) using production site geographic data from the emissions data. I then utilize decades worth of mandatory reporting disclosures to assess shifts in how firm's disclose the risks and opportunities they perceive related to climate change and decarbonization to assess the third hypothesis. In both event study designs, I consider the announcement of the Industrial Decarbonization Challenge as a break point and compare firm behavior before and after. As a final quantitative analysis, I utilize a word-embedding-based regression approach to contextualize how attention to climate change and decarbonization has shifted among association participants. I then introduce the fieldwork and interview research designs.

Cooperation Data and Design

The cooperation data presented in this paper results from an original data collection effort. I provide more details on the data generating process in Appendix A. In brief, combining emissions and geographic data of UK ETS regulated firms, I created a grid-cell based concentration map. Figure 3 presents this map. For each grid cell, I utilized a common battery of search terms related to decarbonization and cooperation alongside geographic names specific to the grid cell.[16]

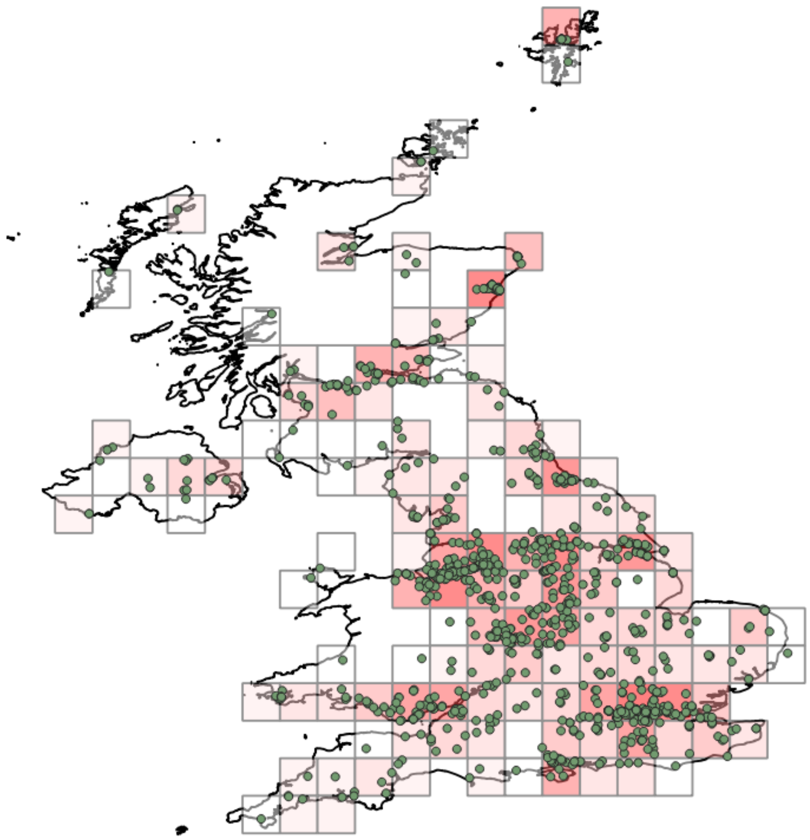
To measure cooperation, I generate a binary indicator variable that takes a value of one if there is a cooperative endeavor among firms towards industrial decarbonization in

[16] The specific search call was (decarbonisation | low carbon | net zero | emissions) AND (cluster | hub) alongside the geographic labels, for example major cities or district council names.

a given grid cell. In practice, this consisted of typically a web page or a LinkedIn profile dedicated towards industrial decarbonization in the area that is led by firms, but not a local government initiative.[17] Given that this binary measure may mask important differences across cooperative initiatives, I coded several other variables to proxy for the depth or intensity of cooperation (Downs, Rocke and Barsoom, 1996). First, if mentioned, I collected the net-zero target year to capture the ambition of the group. Second, is the first date by which cooperation was publicly announced. Third, I consulted the U.K. Companies House to assess whether the endeavor was publicly registered; given the complexity of the investment decisions and concerns over anti-trust, firms have jointly formed limited liability corporations to cover the ambit of industrial decarbonization. Publicly registering the company is not free and is an alternative measure of more formalized cooperation. Lastly, I collected the names of all participating members in a given cluster.

[17] See for example, the website for the Peak Cluster: https://peakcluster.co.uk/ or the LinkedIn profile of HyNet: https://www.linkedin.com/showcase/hynetnw

Figure 3: Regulated Production Site Concentration in 2018



Inter-firm geographic concentration is measured in a continuous fashion: it is the sum of UK ETS regulated production sites in a given grid cell. To assess any non-linear relationship between concentration, as a proxy for potential group size, and cooperation, I include a quadratic of this measure. For the grid cell analysis, I control for the natural log of all regulated emissions and an indicator for the presence of offshore oil infrastructure. This lets me assess whether distributing commercial risks among several, rather than just a single emission intensive firm is driving the result. I control for the presence of offshore oil infrastructure to account for the greater ease with which a carbon capture and storage facility could be developed. Legacy infrastructure in the North and Irish Seas are considered to be a cost-effective means of developing carbon capture in the British context. My primary analyses use a 0.5 × 0.5 degree grid cell area. The area of such a grid cell is slightly larger than London for reference.

In the analyses below, I subset the data to only include grid cells with at least two regulated firms to preclude increased precision in my estimates from observations in which cooperation, that is collective efforts between two or more firms, is not possible. With these cross-sectional data I estimate the following equation:

$$\text{Cooperation}_i = \alpha + \beta_1 \text{Concentration}_i + \beta_2 \text{Concentration}_i^2 + X_i + \epsilon_i \tag{1}$$

I first consider the full sample as well as a subset that omits any clusters that received backing from the UK Industrial Decarbonization Challenge. This subset lets me assess whether the state can catalyze the formation of business interests along geographic lines without direct fiscal incentives. Evidence consistent with the first hypothesis would take the form of a positive value on the β_1 coefficient. Evidence consistent with congestion and club goods would take the form of a negative value on the β_2 coefficient.

Firm Data and Design

The above analysis provides a first cut at the shifting nature of business coordination with respect to industrial decarbonization. It does not, however, provide much in terms of *who* cooperates and *what* this cooperation means for firm interests. To complement the spatial analysis, I use the list of participants alongside the universe of regulated firms to generate a sample of aspiring industrial decarbonizers in the U.K. context. This lets me assess whether among *potential decarbonizers*, that is regulated firms, we observe a relationship between production site concentration and cooperation, as it may be the case that most cooperating firms are not regulated by the UK ETS.[18] I use two sets of firm-level data to assess who cooperates and whether this has a meaningful impact on the formation of their interests and strategy. I discuss each in turn.

At the firm-level, I reverse the measurement strategy from above. That is, rather than consider the number of firms in a given grid cell, I measure how many regulated production sites are co-located within the same grid cell for each of the firm's production sites. I generate a measure, *Max. Concentration*, which is the maximum value of these production site concentration scores. I interact this with a yearly indicator in an event study design to assess whether firms with production sites located in dense emission intensive production areas are more likely to cooperate. As noted above, I omit for brevity's sake the quadratic term in what follows for these firm-level analyses, but present full results with this squared term in Table B5. Following standard practices, I set the baseline to 2018, as it was the year prior to the announcement of the Industrial Decarbonization Challenge, in the following equation:

[18] I provide greater details on this possibility below when discussing the qualitative evidence.

$$\text{Cooperation}_{it} = \alpha_i + \gamma_t + \sum_{y=-5}^{4} (\beta_y \text{Max. Concentration}_i \times \mathbf{1}_{y=k}) + \epsilon_{it} \tag{2}$$

In Equation 2, *Cooperation* is a time-varying indicator that takes a value of one in the first year that the initiative was formalized. I omit the marginal effect of *Max. Concentration* as it is collinear with the firm fixed effect. Evidence consistent with the second hypothesis would take the form of a positive coefficient on the interactive coefficients after 2018.

Does cooperation result in a meaningful shift in firm interests? To tackle this question, I rely on firm identifiers to collect roughly a decade of annual report disclosures submitted to the U.K. Companies House. I use these standardized, mandatory data as a measure of firm interests or preferences for several reasons. First, all disclosures of firms of a reasonable size must receive a third-party audit, hence they cannot purely be cheap talk. Second, British disclosure regulation has increasingly standardized the form these documents take. In practice, boards must discuss the going risks and opportunities to the firm in the past year in the "Strategic Report" and "Director's Report." I focus on the former as it is a common, mandated disclosure of firm interests on a variety of topics as they pertain to the firm's bottom line.[19]

With this sample of strategic reports, I generate separate variables measuring if climate change or decarbonization are mentioned in this section of the annual report (*Mention*). This outcome variable captures whether firms are increasingly aware of these issues, in a similar vein to other work studying firm climate preferences outside the U.K. context (Sautner et al., 2023; Baehr, Bare and Heddesheimer, 2026). Put differently, firms that include climate or decarbonization in this section are explicitly stating it is of a core interest to business operations. My treatment variable is participation in a cooperative endeavor,

[19] Below, I provide some examples of firms' disclosures related to climate change and decarbonization.

which I treat as fixed in the following event study design:

$$\text{Mention}_{it} = \alpha_i + \lambda_{st} + \sum_{y=-5}^{4} (\beta_y \text{Cooperation}_i \times \mathbf{1}_{y=k}) + \epsilon_{it} \quad (3)$$

Alongside this measure of cooperation, I control for document length, the quality of the OCR scan, as well as firm emissions and turnover. The latter two are fixed using their 2018 values and interacted in a similar fashion to the cooperation indicator. As in Equation 2, my baseline period is 2018, the year prior to the start of the Industrial Decarbonization Challenge. I opt for this strategy rather than a more disaggregated or cohort-based approach (e.g., in the style of Sun and Abraham (2021)) given that not all cooperating firms were also founding members when the data generating process took place.[20] In the case that cooperating firms did not immediately found or join a cooperative decarbonization association following the announcement of the Industrial Decarbonization Challenge this measurement strategy would attenuate the β_y coefficients towards zero, presenting a conservative estimation strategy. Given that sectors may face different risks from climate regulation, I opt for sector-by-year fixed effects to assess whether results are robust to heterogeneous time-trends by industry. Evidence in favor of the second hypothesis would take the form of a positive value on the interactive coefficients following 2018. In both event study designs, robust standard errors are clustered at the firm.

Firm interest as measured by mentions in annual reports is directionally agnostic, that is while *Mention* is informative of firm attention to climate change or decarbonization, it fails to clarify if firms consider these issues as a risk or opportunity, for example. To address this shortcoming of the dictionary approach, I leverage word embeddings in a regression framework to gain insights about the context of the climate change and decarbonization

[20] In Table B6, I demonstrate that the substantive results presented in Figure 7 are robust to this alternative design, albeit with some evidence of violations of parallel trends.

mentions in the strategic reports (Rodriguez, Spirling and Stewart, 2023). The outcome is the embedding of the term, specifically the six word window to either side of the term.[21] Document metadata, specifically submission year, firm ID, cooperation status, and an indicator for post-2019, serve as explanatory variables.

The intuition behind the "a la carte" regression analysis in Rodriguez, Spirling and Stewart (2023) is to consider whether document covariates are predictive of differences in the average embedding of the term. A simple example in the present context is clarifying. If cooperating firms see decarbonization as an opportunity rather than a cost, we might expect that opportunity rather than cost is more likely to appear in the six word window of the term for these firms. Generating average word embeddings across different values of the cooperation variable would lead to opportunity being more highly ranked, that is more frequent, for those firms that are cooperating compared to the non-cooperating baseline. This provides a means of further investigating the shifting nature of firm interests, but with an eye towards *how* firms are considering these policy issues.

Identification

Causal identification in an event-study design, as a subset of difference-in-differences designs, requires that we find plausible that absent variation in firm concentration or cooperation status, trends in cooperation and climate issue attention would not have varied over time between the two groups. A core assumption of this approach is that of parallel trends. While testing the assumption is impossible, comparing differences across groups in the pre-period provides a means of checking for clear violations of this assumption. I provide evidence in Figures 6 and 7 consistent with parallel trends across groups in the years preceding 2018. Given that economic agglomeration is an endogenous process, for

[21] I use term here as a placeholder for climate change and decarbonization for brevity.

example with firms shifting their operations to benefit from greater access to logistics networks and other amenities, I opt for a fixed measure of firm concentration that predates the announcement of the Industrial Decarbonization Challenge. Furthermore, the inclusion of sector-year fixed effects guards against time-varying confounding at the industry-level biasing the results.

Qualitative Research Design

Alongside this quantitative design, I spent several months in England speaking with firms, local governments and business associations about the development of these decarbonization clusters. The motivation of these interviews was two-fold: (1) to substantiate some of the theoretical claims and assumptions, namely related to a production site-based logic of cooperation and of the benefits of geographic concentration, as well as (2) to better understand the variation in the depth, intensity, and success of cooperation between different associations. I provide greater details on the sampling strategy, list of interviews, and research design in Appendix A. In what follows, I focus on the relevant aspects for the second component above.

My fieldwork was split across three areas of varying industrial concentration in England: greater Manchester, Southampton, and Kent. These locations represent areas of high, medium, and low concentration respectively. Within each location, I reached out to decarbonization associations and participating firms, where they existed, to speak with involved individuals about the decision to participate and how the association had developed in recent years. These interviews were of a semi-structured nature, typically beginning with the same few questions and then flexibly adjusting to the responses from a given respondent. In total, I conducted roughly 30 interviews of between 30 to 75 minutes in length. I spoke predominantly with sustainability directors or senior engineers of the relevant production site. The decarbonization associations varied in their development from ones having just received major commitments from government to those that had faltered in their development despite initial seed grants. In total, I spoke with individuals involved in five different associations. I was at times referred to speak with individuals at other decarbonization associations outside these areas. Following these initial interviews in other areas, I relied on a snowballing technique to gather additional perspectives.

Above, in my presentation of the argument, I included evidence from the interviews to substantiate (1) my conceptualization of these infrastructure projects as club goods, (2) the benefits related to production site concentration, and (3) the role of the state in creating a market for these green production processes. In the final section of the results, I use these interview data to inductively provide an explanation for the variation in association development that we observe *between* the groups of firms to complement the more granular *within* firm design above.

Results

Before presenting the results of the event studies, I briefly summarize descriptive trends in the data. These relate to the (1) aggregate relationship between concentration and cooperation at the grid-cell level, (2) the number of firms participating in decarbonization associations and (3) the trends in climate change and decarbonization mentions in the annual reports.

In Table 3 I assess the relationship between grid cell concentration and the existence of a decarbonization cooperative. I find evidence consistent with the first hypothesis: there is a positive association between the number of production sites and the existence of a decarbonization association in a given grid cell. Moreover, in line with decreasing marginal benefits of club goods, I find a negative relationship between the quadratic concentration terms. These results hold when excluding association present in areas initially designated by the IDC as evidenced by Models 3 & 4, suggesting an indirect or catalyzing effect of policy. The square brackets present standardized coefficients that allow for direct comparison between the predicting variables, given that they are continuous, binary, and logged. For both the linear and quadratic measure of concentration there is a strong relationship with cooperation, aggregate logged emissions has a positive, albeit weaker effect on cooperation. Given the substantive focus on emission intensive firms that cross the regulatory threshold, it is unsurprising that emissions is not as strong a predictor of cooperation among this sample of firms. This cross-sectional data is consistent with the first hypothesis: the relationship between concentration and cooperation is positive.

Figures 4 and 5 visualize the cumulative number of firms participating in decarbonization associations and the sample average of climate change and decarbonization mentions in the annual reports respectively. Beginning in 2020, we see a sharp increase to roughly 200 participating firms by 2023. Roughly 20% of these firms are regulated by the UK ETS with the remaining 80% being composed of energy intensive firms that fall below the 10Mt CO_2 per year threshold or auxiliary firms to the low carbon value chain, typically from the engineering consulting industry. While cooperating firms only compose about 8% of those facing regulatory scrutiny, they represent nearly a quarter of all regulated emissions in the UK as of 2018. The vast majority of firms participate in a single association, however there are several firms participating in multiple; the maximum membership is four. Most associations are small, featuring between 5 to 15 firms, with a single outlier being the Solent Cluster which has over 100 participating members as of 2024.

In terms of descriptive trends in the disclosure text data, roughly 15 to 25 percent of the firms in the sample mention climate change in a given year with this number leveling off beginning in 2019. Far fewer firms mention decarbonization with only 5 to 8 percent

Table 3: Industrial Concentration and Cooperation

	Model 1	Model 2	Model 3	Model 4
Concentration	0.01	0.03***	0.00	0.03**
	(0.01)	(0.01)	(0.01)	(0.01)
	[0.17]	[0.94]	[0.10]	[0.86]
Concentration^2		−0.00***		−0.00**
		(0.00)		(0.00)
		[−0.68]		[−0.60]
Logged Total Emissions	0.05***	0.04***	0.04***	0.03**
	(0.01)	(0.01)	(0.01)	(0.01)
	[0.38]	[0.27]	[0.27]	[0.19]
Offshore Oil	0.12	−0.12	0.44	0.27
	(0.40)	(0.43)	(0.37)	(0.43)
	[0.07]	[−0.07]	[0.26]	[0.16]
N	127	127	104	104
IDC Winners Included?	✓	✓	⊗	⊗
Grid Cell FE?	✓	✓	✓	✓
R^2	0.67	0.72	0.48	0.55
Adj. R^2	0.41	0.49	0.01	0.12

OLS regression results. The outcome variable is a binary indicator for whether a decarbonization association exists in a given grid cell. 1 degree by 1 degree cell fixed effects included in all models. Robust standard errors in parentheses. Square brackets denote standardized beta coefficients. Models 3 and 4 omit grid cells with decarbonization cooperatives directly funded by the Industrial Decarbonization Challenge. $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

mentioning it prior to the start of the IDC. After 2019 there is a positive trend with roughly 13 percent of firms including decarbonization in their disclosures as of 2023.

Figure 4: Cumulative Total of Participating Firms

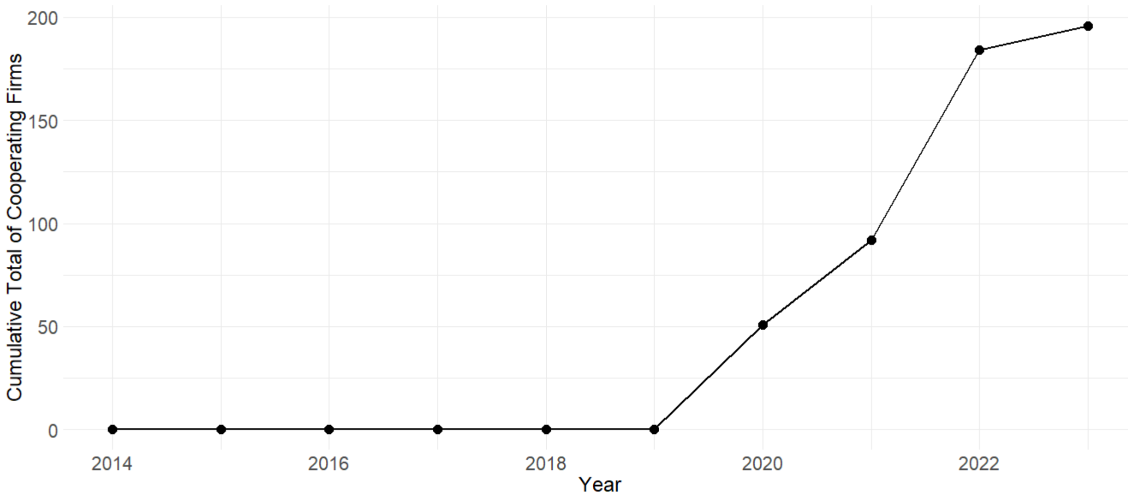
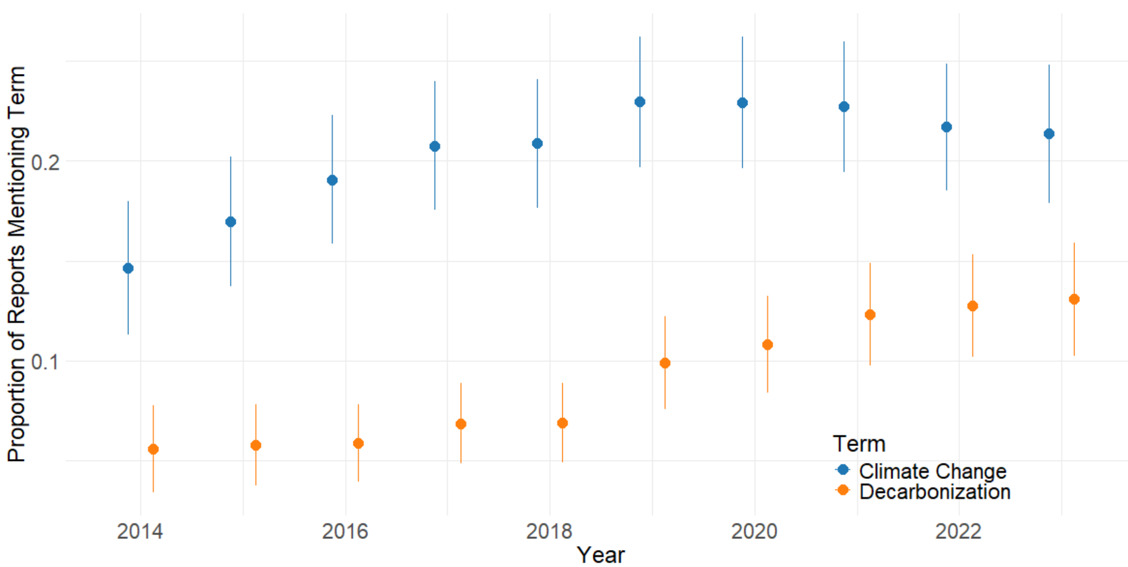
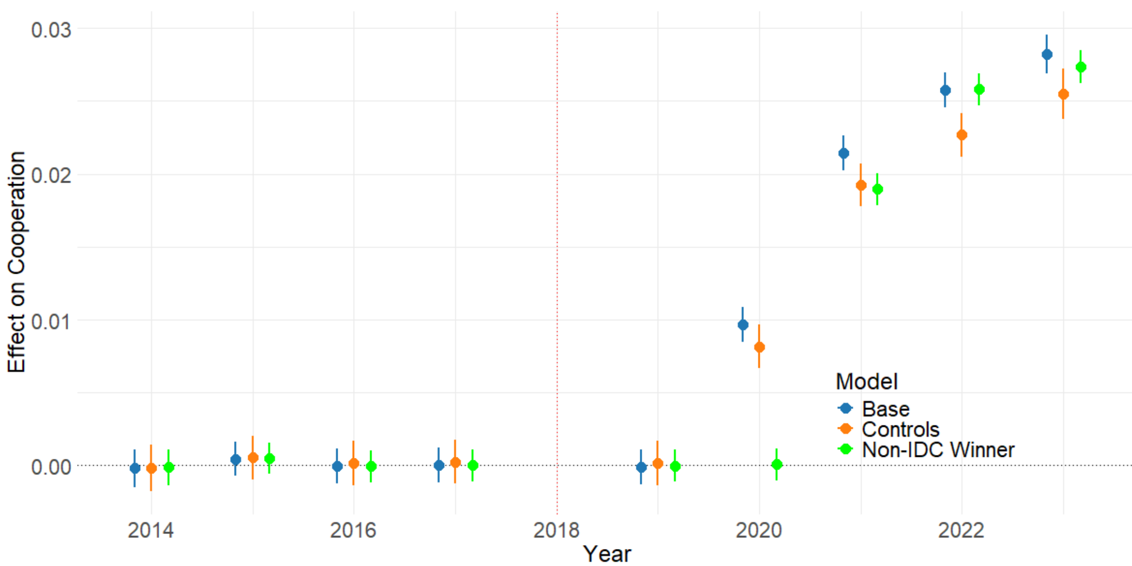


Figure 5: Annual Reports Mentioning Climate or Decarbonization



Thus far, I have provided descriptive evidence of a relationship between areas of emission intensive industrial agglomeration and cooperation alongside an increase in firm interest and attention to climate change and decarbonization. I now provide more rigorous evidence of the impact of geography on a firm's propensity to engage in public good provision through state-led efforts at green development. In brief, in both event study designs I find evidence consistent with the above argument: firms with a production site in a highly concentrated industrial area are more likely to cooperate after 2019, and these cooperating firms are more likely to mention climate change and decarbonization in their disclosures. These cooperating firms mention these terms in a more favorable light than their regulated, but non-cooperating peers.

Figure 6: Firm Concentration and the Likelihood of Cooperating



Note: Point estimates from OLS regressions as specified in Equation 2. Controls include emissions and turnover interacted in an analogous event study design. Non-IDC winner omits firms participating in a cooperative funded by the IDC. Bands represent 95% confidence intervals. See Table B2 for full results.

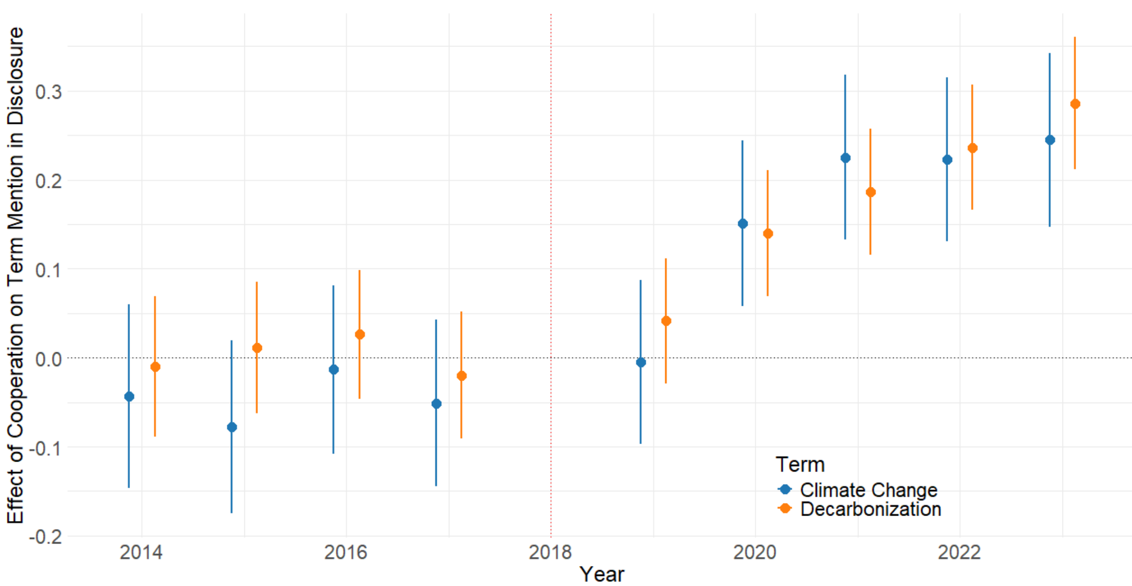
Figure 6 presents the results of the event study. I present three sets of coefficients: with and without firm-level controls as well as a separate indicator for non-IDC targeted decarbonization associations. Full results as well as two-period difference-in-differences estimates are reported in Table B2. Recall that the explanatory variable here is the maximum number of co-located production sites for a given firm. Beginning in 2020, we observe an increasingly positive relationship between the number of highly concentrated production sites and participation in a decarbonization association. While the addition of firm-level financial covariates interacted in a analogous event study design slightly attenuates the relationship between concentration and cooperation, the substantive interpretation does not change. In Table B5, I provide evidence of a negative point estimate on the squared concentration measure for these same firms following 2019.

There is variation in terms of the reaction to this state-led effort to foster business associations for industrial decarbonization. Subsetting to omit the firms not participating in IDC-nominated associations, I find a delay in relationship between concentration and cooperation, suggesting that these firms reacted, rather than anticipated, this announcement. Interview evidence corroborates this lack of anticipation on the part of non-IDC firms.[22] I discuss this in more detail below. Combined with a lack of pre-trend divergences between firms at varying levels of concentration, this absence of anticipation among firms outside the immediate ambit of the IDC, suggests no clear violations to the identifying assumptions discussed above. Substantively, a one standard deviation increase in the maximum production site concentration (16 additional emission intensive production sites) is associated with a 25 percentage point increase in the likelihood of a regulated firm participating when calculated with the two-period difference-in-differences estimate ($\beta = 0.001$, $p < 0.05$). Together, these results present evidence consistent with the second hypothesis.

[22] Interviews 2 (7/2023), 4 (2/2024), and 21 (3/2025).

Figure 7 visualizes the event study results with respect to the third hypothesis. Point estimates in blue and orange represent climate and decarbonization mentions respectively. In the years preceding the IDC announcement, there is no visible difference in public disclosures related to either term by firms that would eventually cooperate versus those that do not. Following 2019, we observe a clear increase in the likelihood of mentioning either term by those cooperating firms. Given that the constituent terms in the interaction are binary variables, the results can be interpreted directly: cooperating firms were roughly 20 to 30 percentage points more likely to mention these terms when discussing the going risks and opportunities to the firm. State-led efforts appear to have shifted the interests of business following cooperation.

Figure 7: Cooperation and Disclosure References to Climate Change and Decarbonization



Note: Point estimates from OLS regressions as specified in Equation 3. See Table B3 for full results.

What exactly did these climate or decarbonization disclosures reference? I briefly provide some examples before turning to the word embedding regression. Progressive Energy

Ltd. is a self-described "low carbon development group" and project lead in decarbonization clusters in the North of England (e.g., the Peak and North West Clusters). In its 2023 Review of Business, the board of directors note that the previous "year saw continued significant advances in both the CCUS (carbon capture utilization and storage) and hydrogen project portfolios resulting in the large reduction in the development risk for key projects" (p. 2). After detailing developments in the HyNet project, a major component of the IDC-backed North West Cluster, the report continues its discussion of the business environment stating, "the primary risk is a change in Government policy to deprioritize CCUS and hydrogen. However the risk has reduced considerably in this reporting period...this [funding support], and the strong cross-party support, reduces the risk. However the risk of delay and budget limitations remain" (p. 2). The report further notes that the importance of the legally binding 2050 net-zero target and the support of the Committee for Climate Change as essential for the reduction of investment risk.

Did the discussion of climate change and decarbonization change in a systematic fashion following firm cooperation? Figure 8 presents normalized coefficients of the association between document covariates and the word embeddings for three terms of interest: (1) decarbonization, (2) climate change, and (3) strategic report. I include the latter as a placebo term, given that it is a standard term that is included in all documents, thereby providing a means of assessing whether cooperating firms following 2019 differed more fundamentally in their disclosure practices.[23] I provide further details on the empirical strategy and text pre-processing for this word embedding analysis in Appendix A. The covariates of interest are: an indicator for disclosures submitted post-2019, an indicator for disclosures from cooperating firms, and indicator interacting these two terms.

The magnitude of the point estimates in Figure 8 provides a sense of how different

[23] Given the relatively low number of documents that feature decarbonization and climate change, 208 & 331 respectively, I omit confidence intervals as over-coverage is unavoidable (Green et al., 2025).

the average embedding is from the omitted group (non-cooperators, pre-2019), but are not directly interpretable in terms of specific terms (Rodriguez, Spirling and Stewart, 2023). For both climate change and decarbonization, cooperating firms differed from non-cooperating firms and continued to do so following the announcement of the IDC and their participation in a decarbonization association. This aggregate shift in context is strengthened not only by the lack of shift following 2019 among non-cooperators as the *Post*-2019 is close to zero across all terms, but the magnitude of the point estimates is also nearly an order of magnitude smaller for the placebo term. Put differently, all firms in the sample contextualize strategic report in a relatively similar fashion compared to decarbonization and climate change.

Figure 8: Document Metadata and Varying Contexts

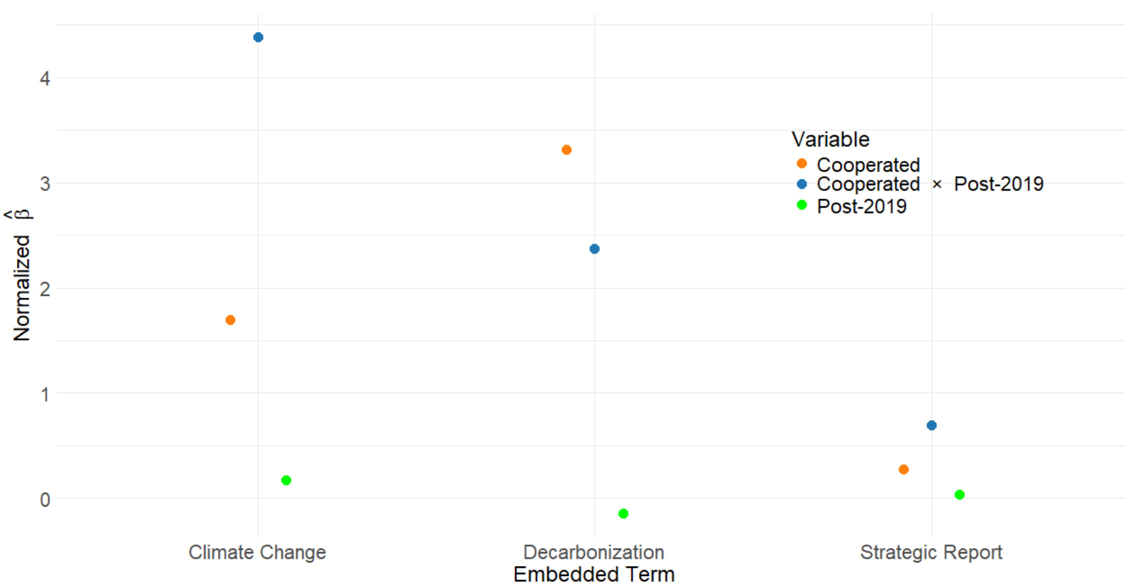


Table 4 presents the 10 nearest neighbors of decarbonization and climate change by cosine similarity across four groups of firm-year observations: (1) non-cooperating firms before and (2) after 2019, and (3) cooperating firms before and (4) after 2019. Across all four groups there are commonalities: many firms speak about decarbonization quickening in pace and emphasize emissions when speaking about climate change. Given that the sample is partially composed of firms that are regulated by the UK ETS this is reassuring–these firms face similar regulatory pressures and should not therefore drastically differ in their discussion of these issues, especially pre-2019. Among non-cooperators, there are fewer changes in the context around the terms of interest; the first six terms for decarbonization are exactly the same, and barring a reordering of energy and emissions the first five are also the same for climate change.

Among cooperators, we observe a larger shift in context for both terms. Decarbonization is more likely to be framed in terms of infrastructure, capabilities and technology in the post-2019 period in line with a focus on developing infrastructure projects that utilize novel technologies such as carbon capture and hydrogen, as the example above demonstrates. In terms of climate change, decarbonization is the 8th most similar term alongside a larger focus on sustainability. In Table B7 I provide the top 10 terms for strategic report. For this placebo term, 9 out of 10 of the top ten terms are the same with slight variation in the order for both non-cooperating and cooperating firms. This lack of variation in contexts is in line with the more modest point estimates in Figure 8 which capture the extent of difference.

Table 4 provides an overview of the most frequent means by which firms described decarbonization and climate change between 2014 and 2023. These top contexts make it challenging to capture trends within *specific* contexts between the cooperating and non-cooperating firms over time. Figures 9 and 10 visualize these group level trends in cosine similarity for each reference term with a set of six words: infrastructure, invest, opportunities, profit, reductions, and risks. These terms were selected to capture business motives and in the case of infrastructure and reductions were selected from the top nearest neighbors

Table 4: Top Nearest Neighbors by Group

Rank	Pre + No Coop	Post + No Coop	Pre + Coop	Post + Coop
		Decarbonization		
1	accelerating	accelerating	accelerating	accelerating
2	electric	electric	growing	electric
3	accelerate	accelerate	electric	accelerate
4	markets	markets	battery	infrastructure
5	growing	growing	markets	capabilities
6	leading	leading	traditional	markets
7	changing	scale	leading	technology
8	scale	battery	mobility	growing
9	increasing	changing	capabilities	scale
10	developing	emerging	focusing	battery
		Climate Change		
1	carbon	carbon	carbon	carbon
2	energy	emissions	renewable	climate
3	emissions	energy	energy	energy
4	climate	climate	emissions	zero
5	renewable	renewable	climate	sustainability
6	environmental	zero	electricity	renewable
7	footprint	footprint	government	sustainable
8	zero	sustainability	zero	decarbonisation
9	greenhouse	environmental	greenhouse	environmental
10	sustainability	greenhouse	reduce	towards

above. Higher values of cosine similarity denote that a given word is more likely to feature in the six-word context window with the term of interest. For example, in the upper-left panel of Figure 9 non-cooperating firms were more likely to associate infrastructure with decarbonization prior to 2019, but this has since flipped.

Figure 9: Changing “Decarbonization” Contexts

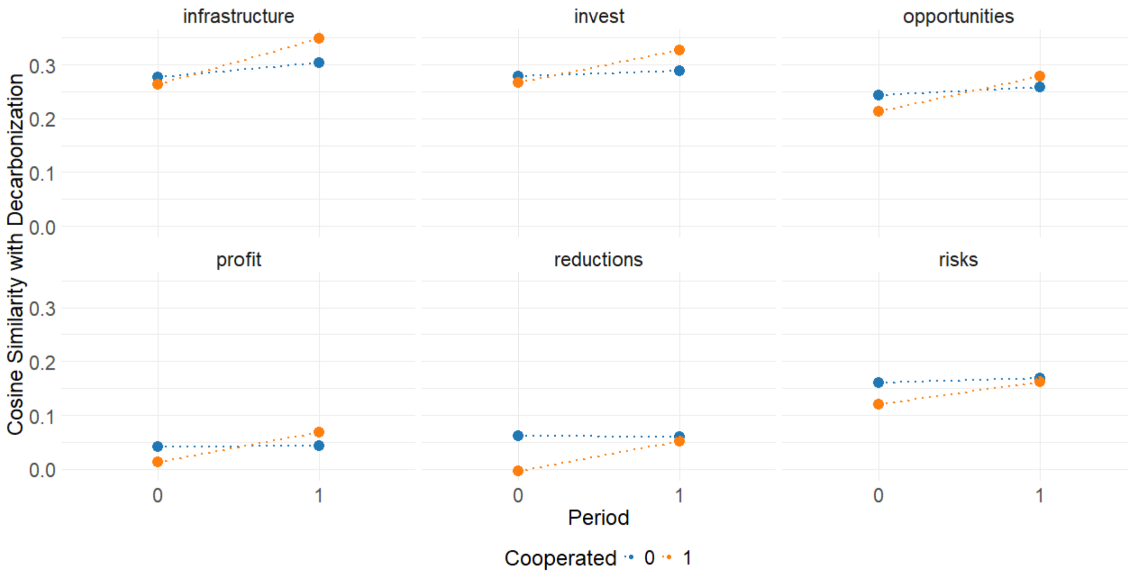
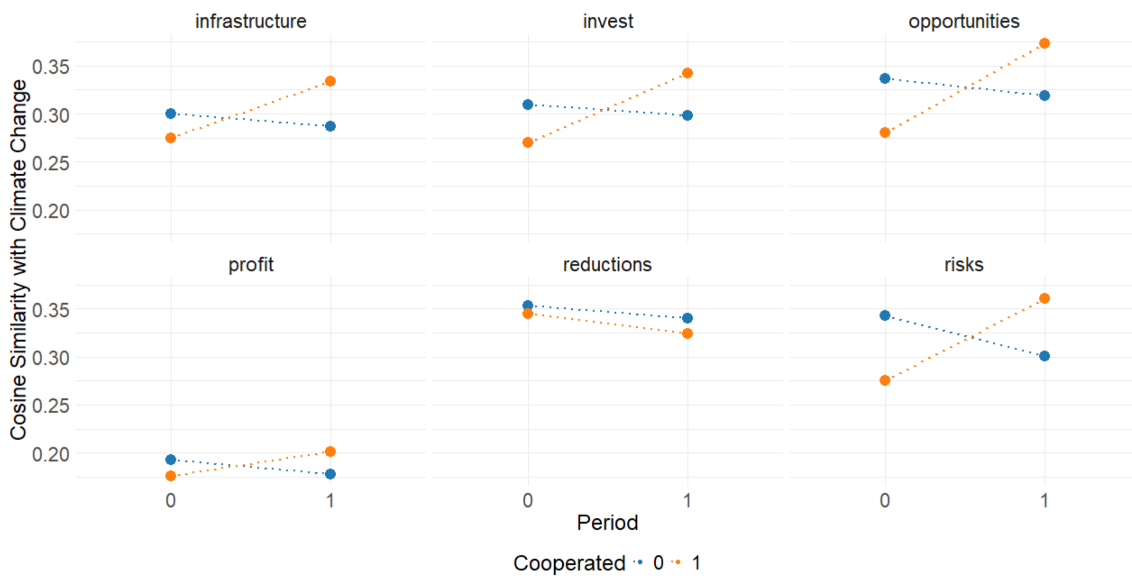


Figure 9 demonstrates that cooperating firms increasingly associate decarbonization with infrastructure, investment, and opportunities but also risks in the years after 2019. The increase in both risks and opportunities is indicative of a more dynamic business and policy environment; cooperation and ultimately investment naturally create a situation in which firms have more opportunities and risks associated with decarbonization. There is likewise a more moderate increase in the usage of the term profit, as well as decreases across both groups with the term reductions. In contrast to their cooperating peers, there is a more uniform decrease in cosine similarity over time among non-cooperating firms, suggesting a reordering of business interests related to decarbonization.

Figure 10: Changing "Climate Change" Contexts



We see similar trends with respect to climate change, albeit to a greater extent, in Figure 10. Given that decarbonization is one of the nearest neighbors to climate change among cooperating firms in the post-2019 period, these similarities are unsurprising. This broader context around climate change and decarbonization is evident in disclosures such as Lhoist's, a cement firm also participating in the Peak Cluster, when it notes "The Company [Lhoist] recognises that manufacturing lime leads to CO2 emissions from the chemical conversion of the stone (process emissions) and from the use of fuels that provide heat for reactions (combustion emissions). Today, without fully developed Carbon Capture, Usage and Storage (CCUS) solutions the process emissions (that represent ≈76% of the lime CO2 output) are unavoidable. This means our initial efforts to decarbonise will focus on energy efficiency, selection of the best kiln technologies and the fuels with lower carbon emissions" (p. 11). The report expands on CCUS below stating, "to implement carbon capture and transition to renewable fuels, the Company [Lhoist] will need to access new infrastructure to transport and store CO2, oxygen and hydrogen... several initiatives are underway to explore the engineering challenges, cost structures and siting issues. By taking an active role in these projects, we are ensuring that our production sites will be ready for integration into this global infrastructure" (p. 11). The report proceeds to discuss Lhoist's participation in the Peak Cluster. While the above quotes are more expansive than the six-word window used in the above analysis, the richness of the annual reports in terms of the issue of climate change and decarbonization is evident.

Figure B6 presents analogous results for the strategic report term. In line with the attenuated normalized coefficients in Figure 8, the shift in cosine similarity among cooperating firms is near-flat for each of the terms. Cooperating firms did not necessarily shift their disclosure practices writ large, but rather on specific aspects related to decarbonization and climate change. These results from the word-embeddings enrich the event study results above: not only did cooperating firms increasingly discuss decarbonization and climate change in their mandated disclosures, but they also increasingly framed these issues around infrastructure and investments in line with a more dynamic business and policy space. Rather than decarbonization purely being an increasingly looming risk to firms, it is an opportunity, in particular for those firms that have entered into decarbonization associations, but not necessarily those firms facing regulatory risk.

The Depth and Intensity of Cooperation

Does all this industrial decarbonization cooperation look the same in practice? And why has decarbonization infrastructure developed in Manchester, but not South Wales or Southampton? To assess the contours of infrastructure collaboration, I conducted 3 months of fieldwork in the U.K. in the spring of 2025. Split between different parts of the U.K.s industrial landscape, I interviewed individuals at roughly 30 industrial firms as well as a handful of individuals affiliated with local government and business associations. From these interviews, I generalize two characteristics that help to explain the variation in the depth of cooperation and extent of infrastructure development across the various associations identified above. First, beyond the impacts of industrial geography elaborated above, concentration, in particular when emissions are balanced across several, rather than one, large emitters, makes cooperation more resilient to defection. Put differently, it better ensures that a critical mass is viable even after an individual firm's production site leaves the association. Second, cooperative entrepreneurs expedite progress by shouldering some of the early costs of cooperation. The emergence of these cooperative entrepreneurs is at times endogenous to concentration as these actors identified promising potential collaborations given the existing concentration of industry. I discuss each in turn below.

Beyond allowing for collective visions of green production, the concentration of industry impacts cooperation outcomes by improving the resilience of the association to defections. By defections here I mean unilateral decisions to end participation. This might occur for various reasons, for example due to factory closure, individual decarbonization efforts, or a shift in production away from carbon intensive products. This defection can undermine cooperation when it threatens what many interviewees described as the associations "anchor", "baseload" or "minimum viable" project. As club goods, infrastructure projects such as carbon capture or hydrogen are not commercially feasible below a certain scale, meaning that without a sufficient baseline number of participants, cooperation will not emerge. Having a wider pool of large emitters reduces the risk of any single defection pushing the project below this threshold.[24] Whereas HyNet progressed without delay following the closure of key participant, and the largest local emitter, CF Industries Holdings in 2022, the progress in other clusters such as the South Wales Industrial Cluster slowed following

[24]Interview 9. 2/2025.

Tata's decision to decarbonize unilaterally in 2024.[25] In the latter case, this investment decision led to a stagnation in collaboration as member firms "went back to looking at what we can do as individual businesses, so it wasnt as collaborative as it could and should have been." This was partially attributable to the "nature of business and the geography" in South Wales, namely the more dispersed concentration of industry compared with elsewhere in the U.K.[26] This is not to say that the closure of CF Industries was irrelevant, but rather that the diversity and density of concentrated emitters allowed for a more resilient collaboration between firms in the Manchester area.

Alongside this increased resilience, deeper collaboration was greatly facilitated by what I refer to as cooperative entrepreneurs, actors who bore additional costs at early stages to push forward cooperation. In many cases, these were either engineering consulting firms or academics who were able to navigate between firms given that they did not have a direct financial interest in a specific participating firm, rather their incentives were tied to the overall functioning of the association and its decarbonization projects. Given that they are not industrial firms themselves, these actors are more easily trusted by potential participants, but also government actors.[27] Many participating firms noted they had little if any prior contact with the other participating firms. Given that social trust and relationships take time to build, cooperative entrepreneurs help to offset these fixed costs to cooperation by facilitating early meetings and better ensuring that a minimum viable project was reached.

In the case of HyNet, many interviewees immediately described Progressive Energy as taking on this role. Having initially brought firms together to consider the project prior to

[25] Interviews 7 (2/2025), 10 (2/2025), & 21 (3/2025).

[26] Interview 21. 3/2025.

[27] Interview 12. 3/2025.

the announcement of the IDC, early meetings served to “develop trust and a strict set of rules related to what can and cannot be discussed within the consortium to comply with competition law.[28] In the case of other clusters, prominent business community members were recognized, but with the acknowledgment that as individuals they only have so many resources.[29] One sustainability executive in the South Wales Cluster when comparing their experience with that of HyNet remarked, “[Progressive Energy] they are the glue that holds it together, here [South Wales] we lack that.[30] This is not to say that South Wales will not ultimately succeed in decarbonizing its industry, but it has not developed as quickly as HyNet in part due to the unilateral deviations by large emitters as well as the absence of a cooperative entrepreneur. Both regions were targeted as “winning clusters by the IDC, but their paths have since diverged. This middle ground that entrepreneurs occupy, neither industrial firms nor traditional business associations, improves their credibility within the industrial decarbonization space, both in terms of the local community and business space but also vis-à-vis national government, as one respondent remarked, these entrepreneurs are “not big oil, which helps with that.”[31] Where these “less-interested” entrepreneurs are not present, for instance in the Solent Cluster, concerns about domination by oil and gas firms such as Exxon Mobil emerge.[32]

Thus far, Ive attributed this variation in cooperative progress at least partially to two factors: not only the concentration of emissions, but also their distribution, as well as the presence of cooperative entrepreneurs. Are these factors additive or interactive? In speak-

[28]Interview 11. 2/2025.

[29]Interview 21. 3/2025.

[30]Interview 21. 3/2025.

[31]Interview 12. 3/2025.

[32]Interviews 11 (2/2025), 17-19 (3/2025). This was also a common remark during informal conversation at decarbonization events when discussing different clusters.

ing with individuals associated with the development of decarbonization associations, it became clear that early discussions related to joint infrastructure projects for decarbonization predate the announcement of the IDC. Preliminary conversations related to HyNet for instance began as early as 2015; the greater Manchester area was prioritized over other emission intensive areas by Progressive because of its concentration of emissions, but also the close presence of other geological assets, for example off-shore oil wells in the Irish Sea and on-shore saline aquifers.[33] This suggests that entrepreneurial presence can at times be downstream of industrial concentration given that it provides fertile conditions for a compelling business case. This is not to say that these factors are necessary, however. As one project developer remarked, when asked about the replicability of this collaborative approach, "It is a replicable model in places with significant groupings of energy intensive industry."[34] This model requires some level of state intervention, however, to provide an initial nudge through market creation (see Table 2).

Conclusion

Under what conditions do private actors provide public goods related to climate change? And what effect do state efforts via green industrial policy have on this process? The theory and evidence presented above have direct implications for these questions. Whereas existing research highlights the short-term competitive forces that drive firms to supply public goods via private means (Kennard, 2020; Perlman, 2020; Gulotty, 2022; Brutger, 2024), I extend this logic to a cooperative framework by conceptualizing decarbonization infrastructure projects, ones that offer steep reductions in carbon emissions, as *intermediate club goods*. This conceptualization suggests that a more concentrated grouping of production sites

[33] Interview 12. 3/2025.

[34] Interview 11. 2/2025.

will facilitate cooperation and the development of decarbonization projects. Given the substantial green productivity benefits inherent in these projects, these cooperating firms' interests related to climate change and decarbonization should shift.

Using a decade's worth of corporate data, I demonstrate that concentrated firms behave in a fundamentally different fashion compared to their more isolated peers. This behavior is driven not by firm-wide characteristics, but varies across production sites. This cooperation has already led to substantial commercial investments by both firms and the British government. It likewise has the potential to drastically reduce CO_2 emissions, representing meaningful pollution abatement. While the UK has been an early mover with respect to these technologies, other countries are also considering GIPs to facilitate their development. Given that industrial production continues to represent between a fifth and third of national emissions in many developed countries today, understanding the political and economic dynamics that better enable firms to reduce emissions is of importance beyond the theoretical contributions this chapter makes to our knowledge about business and politics.

My focus on production sites as a key source of variation in explaining firm behavior has clear implications for the study of climate politics, but also business in politics more generally. Rather than considering firms as unitary actors, the approach developed above stresses that firms are flexible across their production sites. Given the multi-nationalization and expansion of large firms, this suggests that firm strategies have become increasingly diverse *within* the firm, just as they have become more varied between firms in the same industry (Kim, 2017; Kim and Osgood, 2019; Kennard, 2020). The present case focuses on a single case, the UK. Yet even within a single economy I provide evidence of production site-specific decision-making. With respect to climate politics, this geographic angle suggests a need to expand existing accounts of stranded assets based on emission intensity (Colgan, Green and Hale, 2021), and more broadly to engage with the fact that adjustment costs vary not only *within* the industries (Kennard, 2020; Baehr, Bare and Heddesheimer, 2026; Bayer, 2023), but also *within* firms.

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Appendix

Table of Contents

Data Collection Protocol

In this appendix, I provide details on the data generating processes for both the quantitative and qualitative data collection efforts that are omitted from the main text for the brevity's sake. In the case of the quantitative data, I furthermore provide information about the document preparation and pre-processing undertaken prior to the analyses discussed in the main text. The qualitative section includes a list providing general information on the interviews conducted as well as the protocol for getting into contact with said interviewees. All human subject research in this dissertation was approved under Yale IRB #200035376.

Quantitative Data

This appendix section describes in greater detail the data generating process related to the decarbonization associations, participating firms, and firms disclosures and identifiers referenced in the main text. As mentioned in the main text, a geographic grid-based search was used to identify instances of industrial decarbonization associations. These organizational data provided me with the population of participating firms as of 2023, hence I limit the quantitative analysis to the ten year period between 2014 and 2023.

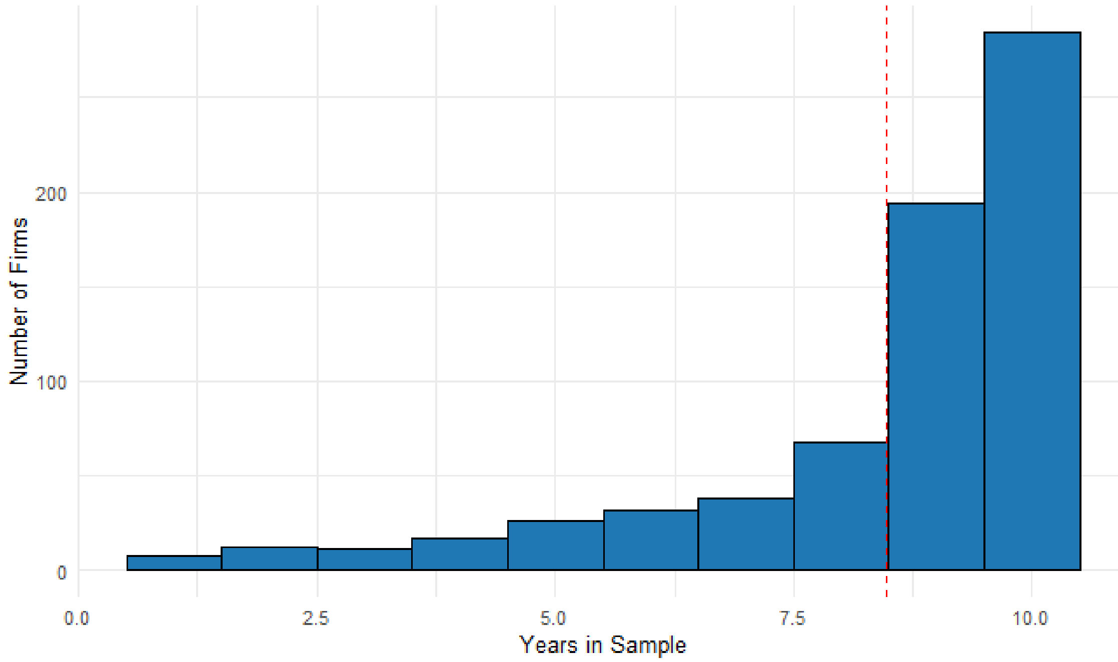
With this population of participating firms, I manually searched and collected the firm business identifier via the UK Companies House business registry database. In some instances, in which the firm name was rather generic or there were multiple instances of firms with similar names, logo-based searches and references to firm websites provided the firm identifier. Business identifiers as well as the geographic location of all emitting production sites is already contained in the UK ETS database, hence these two sources (i.e., cooperating and regulating firms) were merged to generate the final sample for analysis.

The business identifiers serve two purposes. First, they allow me to readily download and incorporate firm financial data from Moody's Orbis. I use these data as control variables in the analyses presented in the main text. Alongside these financial data, the business identifiers let me collect the mandatory annual reports that firms submit to the Companies House via its API server. I elaborate this document retrieval and preparation process in greater detail in what follows.

With the Companies House API and a list of firm identifiers, I was able to collect all available annual reports for the sample of firms between 2014 and 2023. I opt for 2014 as the start date as it was the most recent year after a revision to recording standards, thereafter the strategic and directors' reports that I focus on are standardized allowing for a more interpretable text analysis. Given that some firms incorporated after 2014, the first year of incorporation is when a cooperating or regulating firm enters the dataset. Figure A1 assesses the extent of balance in the sample. Reassuringly, roughly 70% of firms have either nine or ten disclosures available, with over 90% of firms having at minimum six disclosures, meaning there is at least one disclosure on either side of the IDC cut point. The dotted red-line is the mean number of years that a firm features in the dataset ($\approx$ 9). This reduces concerns about whether the panel is sufficiently balanced and therefore appropriate for a difference-in-differences analysis.

With the scraped annual reports, I then OCRed each document to make the scanned text computer-accessible. With these readable documents, I then subset the documents to the strategic reports using a string-based filter process given the common format of the disclosures. First, I selected the second mention of the strategic report given that most disclosures feature a table of contents at the start, hence the second mention is the start of this section. Second, given that the auditors statement of said strategic report immediately follows it, I use the second mention of this term in the text to capture the relevant pages pertaining to the directors' disclosure. This process provides me with the set of pages pertaining to the strategic report for each annual report. I measure two types

Figure A1: Firm-Year Histogram



of document metadata which are included in all subsequent analyses: the number of pages, or length, and the average OCR confidence measure from each page. This comes from the `pdf_tools` package's internal diagnostic of scan quality. Given that I am interested in assessing whether a term is mentioned in the documents, failing to account for either could inflate estimates of the impact of cooperation.

The resulting dataset provides me with a firm-year dataset in which primary variable of interest is the strategic report text from which I measure mentions of "decarboni*" and "climate change" in a binary and count fashion. These serve as the primary outcomes in the event study design presented in Figure 7. Given that I am interested primarily in specific word counts, I omit an text pre-processing for this analysis. For the word embedding analysis, I remove punctuation such as apostrophes and stop words from the text to better capture the unique embeddings across groups. To ease computation, I likewise omit words have fewer than three characters as well as words that feature fewer than 5 times in the corpus of annual reports. Given my focus on average embeddings, such infrequent terms are unlikely to shape the analysis results. These pre-processing steps are consistent with extant word embedding analyses (e.g., Rodriguez, Spirling and Stewart (2023)).

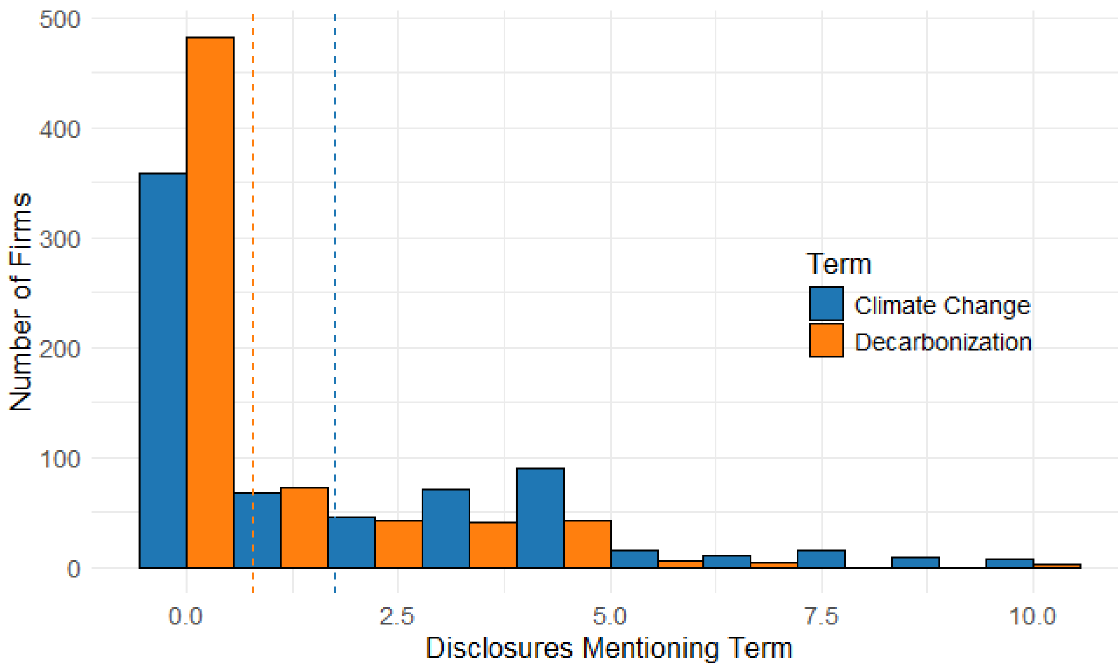
With this set of documents, I pre-train a context specific word embedding corpus. I opt for a local embedding rather than utilizing pre-existing generic word contexts given the specific nature of the corpus. Company disclosure forms differ from the traditional body of text used to train these generalized embeddings: Wikipedia articles. After training the local transformation matrix, I estimate a regression equation of the following form:

$$\mathrm{Y}_{it} = \alpha + \beta_1 \mathrm{Cooperated}_i + \beta_2 \mathrm{Post\text{-}2019}_t + \beta_3 \mathrm{Cooperated}_i \times \mathrm{Post\text{-}2019}_t + \beta_i \mathbf{X}_{it} + \epsilon_{it} \quad \text{(A1)}$$

where Y is the 6-word window embedding of a term of interest and *Cooperated*, *Post*-2019 and their interaction are document indicators for documents pertaining to firms that participated in a decarbonization association, the years following 2019, and their interaction respectively. Alongside these explanatory variables, I include document metadata related to length as well as scan quality as described above.

The β coefficients in Equation A1 capture the group average embedding for firms that either cooperated or did not, before and after 2019; the interaction term is not the average firm-level effect of cooperation following 2019 among cooperators given that I omit firm and year fixed effects in the specification. This omission of fixed effects is motivated for practical reasons: A word-embedding cannot be estimated in the absence of that word, therefore if many firms fail to mention the term or only include the term in one or two disclosures the regression matrix will be singular. Put differently, the fixed effects will often be collinear with the regressors of interest making it difficult if not impossible for the model

Figure A2: Firm-Term-Year Histogram



to converge. I present visual evidence substantiating this sparse data problem in Figure A2 which presents a histogram of the number of firm-term-years for both "decarboni*" and "climate change" in orange and blue respectively. The dashed lines denote the average for each term. For decarbonization this value is 0.77, meaning that the vast majority of documents are omitted from the analysis, and therefore that firm or year fixed effects are more likely to be collinear with the β_3 regressors. Absent these fixed effects, the β_3 term still provides information about the average embedding for cooperating firms following 2019, therefore I provide all four groups (e.g., pre/post, cooperating or not) in the primary analysis to make clear group differences in the average embeddings.

Qualitative Data

In this subsection, I provide additional details related to the qualitative data collection efforts following recommendations from Bleich and Pekkanen (2013). Building on the quantitative data collection elaborated above, I describe the population of interest, the subsequent sampling frame, the interviewing process used, response rates, and finally provide a list of the interviews conducted. Before providing additional details on each of these points, I describe in further detail how the interview data fits into the broader research methodology of the project as these data serve to address both theory testing and building elements related to geographic concentration and cooperation.

I utilize the insights and data from these interviews for two purposes within the broader research design. While policy documents highlight the emphasis on shared costs of infrastructure and the general thrust of cluster-based approach to U.K. industrial decarbonization, it is important to establish that this logic is shared by firms. In this sense, my interviews with firms provided a means of assessing whether some of the core assumptions of theory above are active in boardrooms. This awareness of the decreased costs alongside the magnitude of benefits from deep decarbonization technologies compared with alternative more marginal innovations strengthens confidence furthermore that results connecting concentration with participation and interest expression are not spurious or driven purely by some omitted variable. It was quickly clear to me that sustainability directors and other firm employees were clearly aware of these spatial externalities and economies of scale. Moreover, the distinction between marginal and deep decarbonization potential was a rather banal point in my conversations with firms. Therefore, alongside substantiating my assumptions, I used the interviews to assess variation in the progress or intermediate success of the collaborative efforts between firms which I touch on in the main text. These questions let me assess potential mechanisms and build out a theory that explains variation *across* groupings of firms, rather than explain behavior *within* a given firm over time.

To gain a better understanding of the dynamics of cooperation and its relative success or failure, the population of interest is naturally cooperating firms alongside, more broadly, what I refer to as decarbonization-adjacent individuals. This latter group consists of local or regional business development associations, local government officials, national decarbonization bureaucrats, and cluster leadership. Given that roughly 200 firms were participating in decarbonization cooperatives by 2023, my initial sampling strategy for my fieldwork was to select locations based on varying levels of geographic concentration of industry. For these purposes, I selected the greater Manchester region (high concentration), the Solent Estuary (medium concentration) and Kent (low concentration). In the former two cases, my initial data collection efforts provided me with the population of participating firms. I cold emailed firms and then asked for connections between firms to speak with other companies within these associations who did not initially respond to my requests. In the case of Kent, a small cluster has emerged since 2023, I subsequently collected the relevant contact information for the participating firms from its website and likewise cold emailed these firms.

Beyond this strategy, I was put in touch with individuals at other clusters throughout the UK during the course of interviews. Given that my fieldwork resources were limited, I utilized these connections to speak with individuals affiliated with clusters in Wales, the Black Country, and the Peak Cluster. The South Wales area is an alternative high concentration area. The Black Country is a unique case in that firms here are predominately SMEs, meaning that concentration is very high, but the vast majority of these small energy intensive producers are not regulated by the UK-ETS. My initial conversations with individuals in the Peak Cluster were based on cold emails to separate organizations within the cluster which then referred me to cluster leadership.

Interviews were semi-structured in nature. These varied slightly depending on whether I was speaking with individual firms or other organizations. For these latter groups, I focused on the holistic development of the decarbonization associations from that organization's perspective. In contrast, with firms I asked why they had joined, the costs and benefits of participation, what collaboration looked like in practice, and the role of the government in shaping collaboration. Questions were tailored to cognizant of differences across some of the clusters (e.g., the role of government in Wales versus England). In terms of who I interview, when speaking with firms, I typically spoke with senior engineers currently tasked with decarbonization issues or sustainability directors, who all had engineering backgrounds. In a few cases, I spoke with PR representatives. Interviews were typically 30 to 60 minutes long either in person or conducted via Zoom. All interviews were recorded with simultaneous note-taking. In Table A1, I provide a full list of the conducted interviews broken down by actor type, the date of the interview and whether the interviewee requested anonymity.

Table A1: Interviews on Decarbonization Associations

#	Actor Type	Date	Anonymous?
1	Regulated Industrial Firm	7/2023	✓
2	Regulated Industrial Firm	7/2023	✓
3	Industry Association	7/2023	✓
4	Regulated Industrial Firm	2/2024	✓
5	Industrial Firm	1/2025	
6	Regulated Industrial Firm	2/2025	✓
7	Local Government	2/2025	
8	Regulated Industrial Firm	2/2025	✓
9	Regulated Industrial Firm	2/2025	

#	Actor Type	Date	Anonymous?
10	Regulated Industrial Firm	2/2025	
11	Industrial Firm	2/2025	✓
12	Regulated Industrial Firm	3/2025	✓
13	Regulated Industrial Firm	3/2025	
14	Industrial Firm	3/2025	
15	Industrial Firm	3/2025	✓
16	Cluster Leadership	3/2025	✓
17	Climate Group	3/2025	
18	Climate Group	3/2025	
19	Climate Group	3/2025	
20	Industrial Firm	3/2025	✓
21	Regulated Industrial Firm	3/2025	✓
22	Industry Association	4/2025	✓
23	Industrial Firm	4/2025	✓
24	Regulated Industrial Firm	4/2025	✓
25	Industrial Firm	4/2025	✓
26	Academic Participant	4/2025	
27	Hydrogen Economy 2025 – Liverpool	3/2025	N/A
28	HyNet Annual Conference	3/2025	N/A

Interviews included are only those related to the British context. I omit other interviews from France and Spain on related topics for brevity. I distinguish between regulated and unregulated industrial firms with respect to the UK ETS. Items 27 and 28 are not interviews, but events I attended during my fieldwork during which I spoke conversationally with many more association participants and decarbonization-adjacent individuals.

Additional Firm Level Results

Firm Descriptives

Figure B3: Histogram of Firms by Max Concentration and Cooperation Status

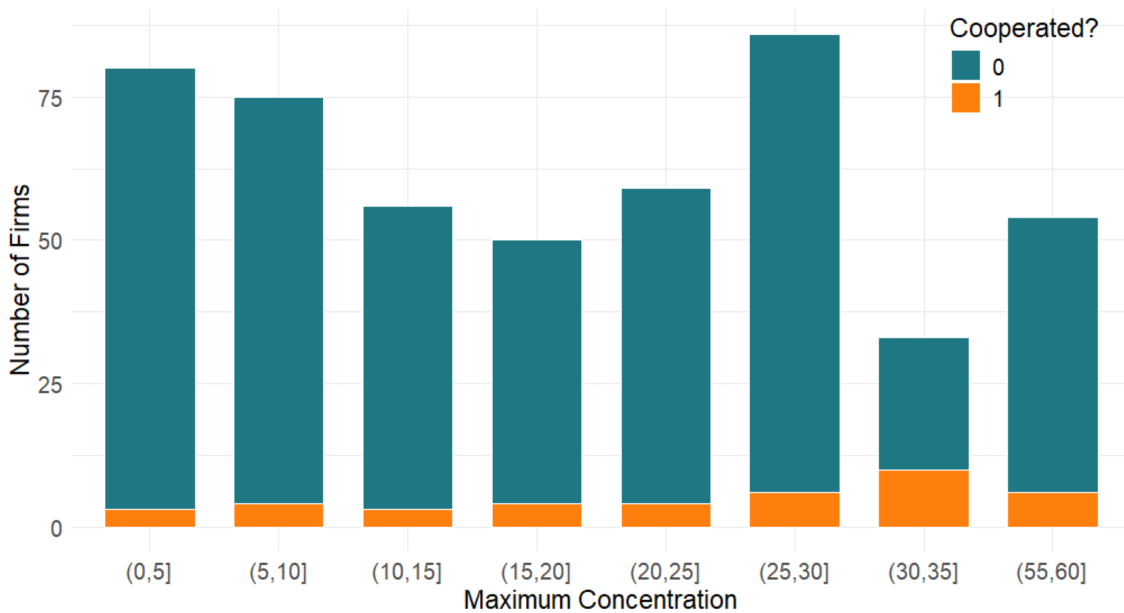
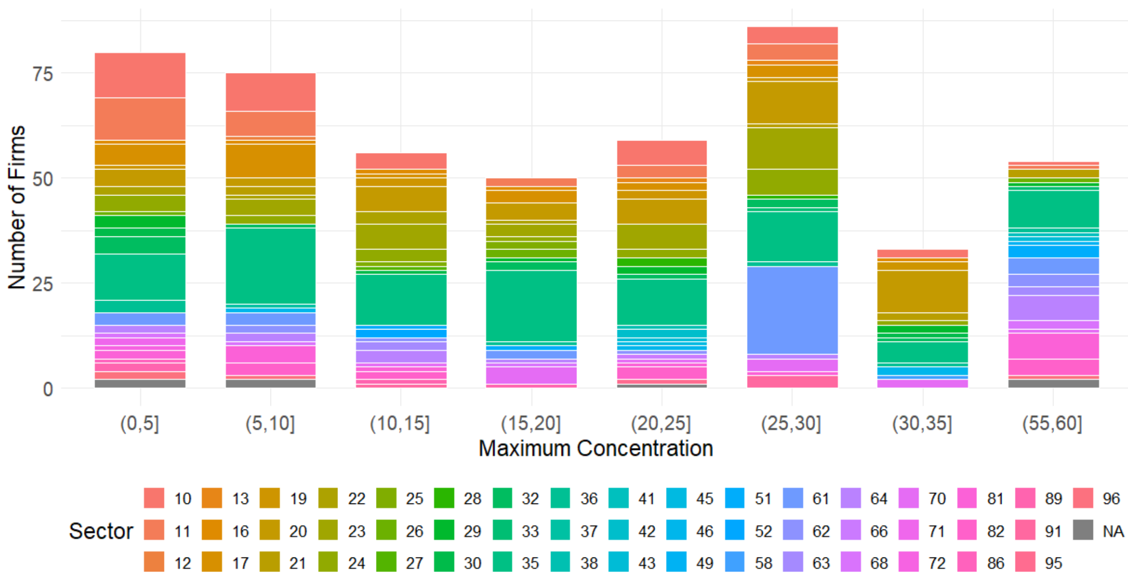


Figure B4: Histogram of Firms by Max Concentration and Sector



Visualization Tables & Robustness

This appendix section presents robustness results for the firm-level analysis. This includes the following: (1) the full regression results to make Figure 6, (2) the instrumental variables analysis, and (3) a replication of the difference-in-differences and event study design with a quadratic term for maximum concentration. In the IV analysis, I use maximum concentration as an instrument for cooperation, with the fitted values from this first stage then used to predict whether a firm mentions decarbonization or climate change in its annual strategic report.

Table B2: Firm Concentration and Participation in Cooperative Initiative

	Model 1	Model 2	Model 3	Model 4	Model 5
Max Concentration	0.001**				
	(0.000)				
Max Concentration × Post-2018		0.001**			
		(0.001)			
Max Concentration × 2014			−0.000	−0.000	−0.000
			(0.001)	(0.001)	(0.001)
Max Concentration × 2015			0.000	0.000	0.001
			(0.000)	(0.000)	(0.000)
Max Concentration × 2016			−0.000	−0.000	0.000
			(0.000)	(0.000)	(0.000)
Max Concentration × 2017			0.000*	0.000	0.000
			(0.000)	(0.000)	(0.000)
Max Concentration × 2019			−0.000	−0.000*	0.000
			(0.000)	(0.000)	(0.001)
Max Concentration × 2020			0.010***	0.000	0.008***
			(0.003)	(0.000)	(0.003)
Max Concentration × 2021			0.021***	0.019***	0.019***
			(0.003)	(0.004)	(0.004)
Max Concentration × 2022			0.026***	0.026***	0.023***
			(0.002)	(0.003)	(0.002)
Max Concentration × 2023			0.028***	0.027***	0.025***
			(0.002)	(0.003)	(0.003)
Firm, Year FE?	⊗	✓	✓	✓	✓
Sector-Year FE?	⊗	⊗	⊗	⊗	✓
Sample?	Reg.	Reg.	Reg.	Non-IDC	Reg.
Clusters	533	533	533	518	505
N	4592	4592	4592	4457	4098
R^2	0.004	0.368	0.747	0.765	0.790
Adj. R^2	0.004	0.283	0.713	0.733	0.723

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

Table B3: Regression Results for Figure 7

	Decarbonization	Climate Change
	Model 1	Model 2
2014 × Cooperated	−0.01	−0.04
	(0.03)	(0.06)
2015 × Cooperated	0.01	−0.08
	(0.03)	(0.05)
2016 × Cooperated	0.03	−0.01
	(0.03)	(0.05)
2017 × Cooperated	−0.02	−0.05
	(0.02)	(0.04)
2019 × Cooperated	0.04	−0.01
	(0.03)	(0.04)
2020 × Cooperated	0.14***	0.15**
	(0.04)	(0.05)
2021 × Cooperated	0.19***	0.23***
	(0.04)	(0.05)
2022 × Cooperated	0.24***	0.22***
	(0.04)	(0.05)
2023 × Cooperated	0.29***	0.24***
	(0.04)	(0.06)
N	5780	5780
Firms	682	682
R^2	0.44	0.51
Adj. R^2	0.29	0.38

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table B4: Instrumenting Maximum Concentration for Cooperation 2SLS

	Decarbonization		Climate Change	
	Model 1	Model 2	Model 3	Model 4
IV × Post-2019	0.21**		0.07	
	(0.08)		(0.11)	
IV × 2014		0.11*		−0.06
		(0.06)		(0.13)
IV × 2015		0.11		−0.28**
		(0.08)		(0.11)
IV × 2016		0.05		−0.11
		(0.05)		(0.11)
IV × 2017		−0.02		−0.16
		(0.03)		(0.10)
IV × 2019		0.06		−0.07
		(0.06)		(0.07)
IV × 2020		0.24***		0.27**
		(0.08)		(0.12)
IV × 2021		0.30***		0.24**
		(0.09)		(0.11)
IV × 2022		0.32***		0.23*
		(0.10)		(0.12)
IV × 2023		0.22***		0.30*
		(0.08)		(0.18)
N	5780	5780	5780	5780
Clusters	682	682	682	682
Sector-Year FE?	✓	✓	✓	✓
R^2	0.44	0.44	0.50	0.51
Adj. R^2	0.28	0.28	0.37	0.37

The outcome is the likelihood of mentioning either climate change or decarbonization in a mandatory disclosure. The F-statistic is greater than 10 for all first stage estimators. All models include firm and NACE-2 industry code by year fixed effects. Robust standard errors clustered at the firm. $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

Table B5: Non-Linear Effects of Production Site Concentration on Cooperation

	Model 1	Model 2	Model 3	Model 4	Model 5
Max Concentration	0.002**				
	(0.001)				
Max Concentration × Post-2018		0.004**			
		(0.002)			
Max Concentration × 2014			0.000	0.001	0.000
			(0.001)	(0.001)	(0.001)
Max Concentration × 2015			−0.000	−0.000	−0.001
			(0.000)	(0.000)	(0.001)
Max Concentration × 2016			0.000	0.000	−0.001
			(0.000)	(0.000)	(0.001)
Max Concentration × 2017			0.000	0.000	−0.001
			(0.000)	(0.000)	(0.001)
Max Concentration × 2019			−0.000	−0.000	−0.000
			(0.000)	(0.000)	(0.000)
Max Concentration × 2020			0.022***	−0.000	0.023***
			(0.007)	(0.000)	(0.008)
Max Concentration × 2021			0.054***	0.050***	0.054***
			(0.006)	(0.008)	(0.005)
Max Concentration × 2022			0.058***	0.058***	0.056***
			(0.004)	(0.005)	(0.004)
Max Concentration × 2023			0.064***	0.065***	0.062***
			(0.004)	(0.004)	(0.004)
MC^2	−0.000				

	Model 1	Model 2	Model 3	Model 4	Model 5
	(0.000)				
$MC^2 \times$ Post-2018		−0.000			
		(0.000)			
$MC^2 \times$ 2014			−0.000	−0.000	−0.000
			(0.000)	(0.000)	(0.000)
$MC^2 \times$ 2015			0.000	0.000	0.000*
			(0.000)	(0.000)	(0.000)
$MC^2 \times$ 2016			−0.000	−0.000	0.000
			(0.000)	(0.000)	(0.000)
$MC^2 \times$ 2017			−0.000	−0.000	0.000
			(0.000)	(0.000)	(0.000)
$MC^2 \times$ 2019			0.000	0.000	0.000
			(0.000)	(0.000)	(0.000)
$MC^2 \times$ 2020			−0.000*	0.000	−0.000*
			(0.000)	(0.000)	(0.000)
$MC^2 \times$ 2021			−0.001***	−0.001***	−0.001***
			(0.000)	(0.000)	(0.000)
$MC^2 \times$ 2022			−0.001***	−0.001***	−0.001***
			(0.000)	(0.000)	(0.000)
$MC^2 \times$ 2023			−0.001***	−0.001***	−0.001***
			(0.000)	(0.000)	(0.000)
Firm, Year FE?	⊗	✓	✓	✓	✓
Sector-Year FE?	⊗	⊗	⊗	⊗	✓
Controls?	⊗	⊗	⊗	⊗	✓

	Model 1	Model 2	Model 3	Model 4	Model 5
Clusters	533	533	533	518	505
Num. obs.	4592	4592	4592	4457	4098
R^2	0.006	0.369	0.828	0.873	0.864
Adj. R^2	0.006	0.285	0.804	0.856	0.819

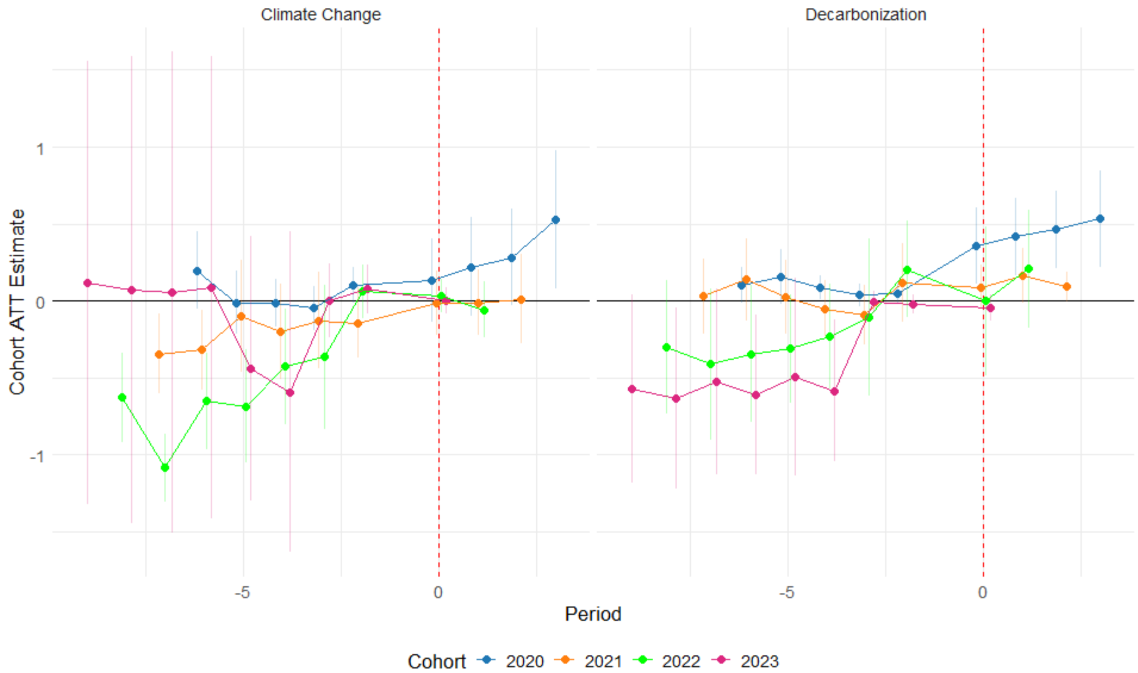
The outcome is the likelihood of a firm participating in a decarbonization association. The sample includes all UK ETS regulated firms. Robust standard errors clustered at the firm. Controls include interactions with 2018 turnover and emissions in an analogous event study design in Model 5. $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

Table B6: Sun and Abraham (2021) Cohort Group Treatment Effects

	Model 1	Model 2
year::-9	-0.57^{*}	0.12
	(0.31)	(0.73)
year::-8	-0.40^{**}	-0.43^{*}
	(0.18)	(0.25)
year::-7	-0.17	-0.55^{***}
	(0.11)	(0.11)
year::-6	0.01	-0.17^{*}
	(0.08)	(0.09)
year::-5	-0.01	-0.17^{*}
	(0.07)	(0.10)
year::-4	-0.06	-0.19^{**}
	(0.05)	(0.09)
year::-3	-0.04	-0.13
	(0.06)	(0.08)
year::-2	0.10	-0.01
	(0.06)	(0.06)
year::0	0.16^{**}	0.05
	(0.07)	(0.07)
year::1	0.27^{***}	0.08
	(0.07)	(0.08)
year::2	0.27^{***}	0.14
	(0.07)	(0.11)
year::3	0.53^{***}	0.53^{**}
	(0.16)	(0.23)
Document Length	0.00^{***}	0.01^{***}
	(0.00)	(0.00)
OCR Confidence	0.00^{**}	0.00^{***}
	(0.00)	(0.00)
N	4531	4531
Firms	526	526
R^2	0.42	0.52
Adj. R^2	0.24	0.38

Robust standard errors clustered at the firm in parentheses. Coefficients denote average cohort treatment effects. $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

Figure B5: Cohort Average Effects



Word Embeddings Robustness

Figure B6: Changing "Strategic Report" Context

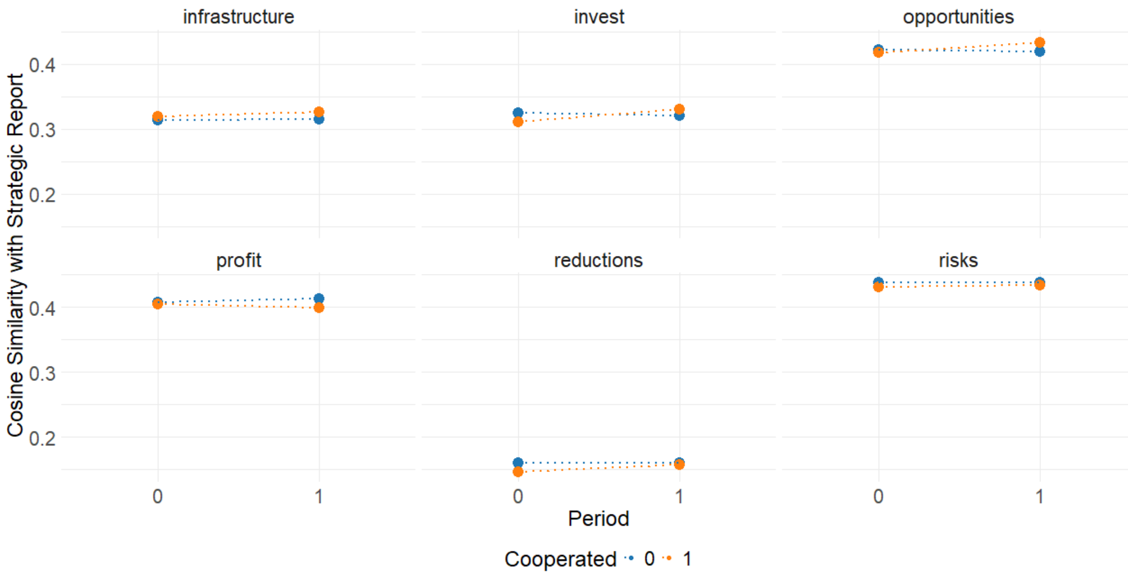


Table B7: Nearest Neighbors for "Strategic Report"

	Pre + No Coop	Post + No Coop	Pre + Coop	Post + Coop
1	report	report	report	report
2	strategic	strategic	strategic	strategic
3	directors	directors	directors	directors
4	contents	contents	information	page
5	information	information	contents	pages
6	director	director	director	contents
7	page	pages	pages	information
8	pages	page	page	annual
9	independent	independent	annual	director
10	annual	board	independent	board

A Additional Context on British Industrial Decarbonization Policy

How has the British government sought to incentivize firms to decarbonize their production processes? And how do these state-led efforts fit into the theory laid out above? In this section, I provide a brief overview of the history of British industrial decarbonization policy since the start of the 21st century, when efforts to seriously decarbonize industry, not just power generation began. In brief, earlier attempts to spur industrial decarbonization focused on demonstration projects that placed the *entire* low carbon value chain within a single firm. This contrasts sharply with recent efforts to diversify the low carbon value chain across various firms and focus on jointly decarbonizing clusters of industry. This shift was led partially by independent audit reports as well as private lobbying efforts towards the geographic model embraced by the Industrial Decarbonization Challenge. I provide greater details on this policy context and what CCS and hydrogen networks are in what follows.

Given ample offshore oil assets, a constant feature of discussions pertaining to British industrial decarbonization is the desire to leverage legacy assets in the oil and gas sector for carbon capture and storage (CCS). This focus on CCS is twofold, it reduces the nature of stranded assets within these fossil fuel sectors, providing jobs for engineers and oil rig workers, albeit this time in the *reintroduction* of carbon to the earth, rather than its *extraction*; and it simultaneously provides the UK with a potential long-term export industry in terms of emissions storage. An added benefit, of course, is that for a country with ample emission intensive industries this provides a cost-effective means of eliminating emissions, in particular in sectors with process emissions, that is those that are inherent to production process rather than coming from power generation sources. For these reasons, CCS has been a constant feature of industrial decarbonization policy in the UK, since the issue first emerged in the early 2000s.

CCS and hydrogen represent two deep decarbonization technologies. By deep, I mean that they fundamentally transform the production process, effectively reducing emissions to zero. CCS is a multi-step process that begins at the production facility and terminates in a permanent storage site, typically an exhausted oil or natural gas well. In practice the process can be split into three separate stages: (1) the capture of emissions at the production site, (2) the transportation of these emissions, and (3) their permanent storage. In the first step, emission intensive firms can adapt technologies, for example chemical scrubbers, that capture the CO_2 emissions from the *mixture* of effluent gases resulting from the production process. I emphasize mixture here as it is important to highlight that industrial production does not result in a gaseous by-product that is purely CO_2, but rather a blend of various noxious gases. Firms, then, must isolate the CO_2 from other gases in the effluent and send it into the transport stage, the concentration of CO_2 in the initial effluent directly shapes these costs.[1] Second, once the carbon emissions have been isolated, they must be pressurized to be safely transported via a pipeline, train, ship, or truck to the permanent storage site. This pressurization is done either on site or at pressurizing station depending on the mode of transport and distance. Finally, after arriving via whichever transport method to the permanent storage location, the concentrated CO_2 gas is pumped several miles underground into the exhausted oil well.

Hydrogen, for decarbonization purposes, is considered a substitute for natural gas in industrial production processes. Currently, hydrogen is used extensively in ammonia and steel production as well as petrochemical refining. Traditional methods of producing hydrogen for these industrial uses rely on splitting hydrogen atoms from natural gas. This "gray" hydrogen, referring to its highly polluting production process, can be replaced by

[1]For instance, in the cement sector, given the high concentration of CO_2 in the effluent by-product of lime calcination, capturing is cheaper than in other sectors with lower concentrations such as steel.

“blue” or “green” hydrogen.[2] The former relies on traditional methods of hydrogen production, but with the addition of CCS, thereby eliminating emissions from the natural gas separation process. The latter relies on using electrolyzers and energy from renewable sources to split hydrogen and oxygen atoms in water. Blue or green hydrogen networks provide industrial users of gray hydrogen or natural gas with a decarbonized alternative to existing production processes. For example, in the paper and glass industries natural gas is currently used for heating purposes: these firms can substitute natural gas with clean hydrogen and eliminate the emissions resulting from the combustion of natural gas.

Early attempts at using industrial policy to create a CCS sector from scratch focused on large scale pilot projects in which individual power generation sites were selected and received extensive public funding to capture, transport *and* store the emissions from either coal or natural gas fired power stations. The most notable example of this industrial policy approach is the White Rose project, which ultimately failed to capture any of the emissions from the power station of the same name due to excessive costs related to transportation and storage of said emissions. Several other demonstration projects likewise failed to reach fruition, leading the National Audit Office in a highly influential 2017 report to conclude that both the first and second bid competitions were failures.[3] This failure was attributed to an inability of individual firms to handle all parts of the low carbon value chain, that is capture, transport, and storage, as one project “could not find a partner for storage” (p. 9), alongside concerns about the credibility of the government’s commitment to price supports.[4]

[2]For a detailed breakdown of the different types of hydrogen production, see: https://www.weforum.org/stories/2021/07/clean-energy-green-hydrogen/.

[3]Informal conversation with bureaucrats of the Department of Energy Security and Net Zero (DESNZ) as well as several engineers emphasized the importance of this document in shifting the UK government’s approach to funding CCS.

[4]The full report can be found here: https://www.nao.org.uk/wp-content/uploads/2017/01/Carbon-Capture-and-Storage-the-second-competition-for-government-support.pdf.

Acknowledging these value chain concerns, the government launched a renewed effort to push industry towards net zero with the Industrial Decarbonization Challenge in 2019. The government adopted a cluster-based approach to decarbonization in which firms, but also local government and research institutions were provided with seed grants to try and develop decarbonization plans that were more regional, or place-based, in nature. This challenge identified the six largest concentrations of emissions in the country[5] and framed it as competition for further rounds of funding and price supports upon the eventual development of industrial hubs based around CCS or hydrogen networks. It is with this policy that the British state tried to forge a territorial-based form of business association with an explicit goal of decarbonization.

[5]The six areas are: North West, Humber, South Wales, Black Country, Scotland, and Teeside.