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Framing industrial decarbonization technologies in the public sphere: narratives from the digital 'town square' in the United Kingdom

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Abstract

Recent research underscores the importance of ensuring that net-zero pathways are perceived as legitimate and socially acceptable, as public attitudes can trigger significant backlash. This article investigates the narratives surrounding industrial decarbonization in the UK within Twitter's 'digital town square.' Intermediary agents play a crucial role in shaping this discourse by fostering debate, offering specialized expertise, and promoting specific technological narratives. Our contribution is twofold: first, we systematically analyze tweets from intermediary agents to identify key technological and economic narratives; second, we employ natural language processing to demonstrate a striking consistency between these narratives and the perspectives of incumbent industries and central government. This alignment suggests that the technological selection of certain decarbonization strategies by both industry and government may undermine the social acceptability of industrial decarbonization technologies and associated infrastructure.

1. Introduction

Achieving net-zero emissions in industrial sectors necessitates policy changes across multiple sectors and is of critical economic and environmental significance. Indeed, the International Energy Agency (2023) estimates that heavy industry accounts for a quarter of global CO2 emissions from energy systems. The World Economic Forum estimates it at 30%, and argues that policies should prioritize technological innovation within industrial clusters to address the decarbonization challenge (WEF 2023).

The imperative to support industrial decarbonization in clusters—which span agricultural chemicals, ceramics, energy and electricity production, manufacturing, glass making, oil and gas production, plastics production, petrochemicals, steel, and iron production— has been increasingly highlighted in recent scholarship (Devine-Wright 2022, Sovacool *et al* 2024a, Sovacool *et al* 2024b). Heavy industry has, nevertheless, historically received less attention compared to other sectors largely due to its classification as 'hard-to-abate' (Svensson *et al* 2020). Yet this viewpoint is now shifting with the advent of a renewed industrial policy (Meckling 2021). Industrial and environmental policies are increasingly converging into what is being termed green industrial policy (Fløysand *et al* 2022), particularly in the United Kingdom (UK) (Dawley 2014, Allan *et al* 2021, Johnstone *et al* 2021).

The UK has set ambitious targets, aiming to establish one low-carbon cluster by 2035 and at least one net-zero cluster by 2040 (HM Government 2021). To achieve these goals, government has earmarked significant financial support to technogical options (*see* figure 1), including but not limited to £170 million for its Industrial Strategy Challenge Fund, £1 billion for its Carbon Capture and Storage Infrastructure Fund, £240 million for the

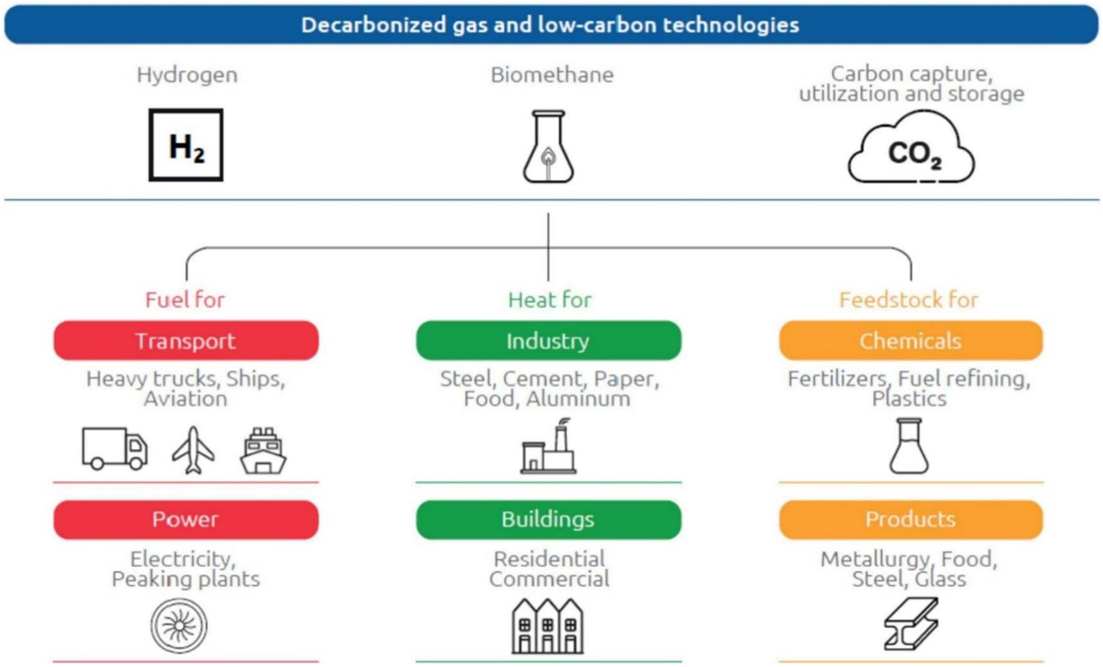

Figure 1. Technological options for industrial decarbonization. source: Griffiths *et al* (2021).

Industrial Decarbonization and Hydrogen Revenue Support scheme, and £315 million for its Industrial Energy Transformation Fund. With billions of pounds on the table, and funding based on a 'cluster competition' framework, technological solutions for industrial decarbonization in the UK are a subject of intense debate (Ringel *et al* 2021, Sovacool *et al* 2023b).

Financial support for industrial decarbonization megaprojects in the UK, however, have thus far largely centered on carbon capture, utilization, and storage (CCUS/CCS), green and blue hydrogen production and transport (Geels *et al* 2023). Green hydrogen is made from renewable energy, while blue hydrogen is produced from methane using CCUS. Although these technologies align well within the incumbent industry regime (Goldstein *et al* 2023), there has been comparatively less emphasis on public attitudes and perceptions of justice and equity, and the overall social legitimacy of these favored technological options and related efforts (Newell *et al* 2022). The risk is signficant: should decarbonization technologies fail to obtain a 'social license' to operate, there is potential for widespread backlash (Buck *et al* 2023, Sovacool *et al* 2023a). This concern is especially salient in the UK, where industrial decarbonization subsidies are funded by taxpayers (Gough and Mander 2022, Turner *et al* 2021).

Intermediary agents are defined as 'supporting organizations' with access to 'external sources of knowledge and specialized expertise,' characterized by their 'extensive network of ties to different parts of a social system' (Molina-Morales and Martinez-Chafer 2016, p. 880). They support regional knowledge infrastructure (Heidenreich and Mattes 2012) and facilitate 'coordination both between public and private agents and between different public agencies' (Martin and Sunley 2003, p. 24). In the context of framing industrial decarbonization technologies, intermediary actors play a crucial role in in garnering support for projects within their respective clusters (Zbuchea *et al* 2018). They create narratives and visions of a decarbonized, regionally-focused, industrial region (Gough and Mander 2022). Against this background, we examine the emerging and dominant narratives that surround industrial decarbonization in the UK's industrial clusters from the perspectives of intermediary agents.

We ask: what socio-technical narratives are emerging in the UK around net-zero clusters? Who are the actors behind these narratives, what common themes exist, and what tensions or areas of contestation are unfolding within these themes? To address these questions, we extract Twitter data from five prominent intermediary agents, one for each of the largest industrial clusters. Though Twitter was rebranded as 'X' in 2023, this article uses the former since the social media platform is more widely recognized by it.

This article is structured as follows. We first outline our rationalale for analysis. We then delve into the utilization of data from social media platforms, the insights that can be drawn, and the dynamics of influence among networks in the digital realm (section 2). We then discuss the methods in section 3. Following this, we conduct a comprehensive review of the existing literature on climate change, sustainable transitions, and the role of social media (section 3.3). Section 4 delivers the results. Section 5 discusses the results, tying back to the UK's cluster and technological focuses, while section 6 is the conclusion.

2. Background and context: sociotechnical debates in the digital town square

Twitter is considered a 'digital town square' that offers a platform for open dialogue and the exchange of ideas (Zarrabeitia-Bilbao *et al* 2023). Consonant with related social media platforms, Twitter is a 'user-driven platform that facilitates the diffusion of compelling content, dialogue creation' and other 'lines of communication to a variety of stakeholders' (Kapoor *et al* 2018, p. 536). Unlike traditional, top-down, and centralized media outlets, social media offer ample opportunities to engage in political discourses and sensitive socio-economic concerns, especially in local settings (Oh *et al* 2015, Wang and Liu 2021). As such, it also enables 'an environment that is conducive for interactions and networking to occur at different levels (for instance, personal, professional, business, marketing, political, and societal)' (Kapoor *et al* 2018, p. 536).

As social media tools have become embedded within the broader social lexicon, the proliferation of narratives in this digital space is beginning to have measurable societal impacts (Ghiassi *et al* 2016, Meire *et al* 2019, Sovacool *et al* 2020). In recent years, indeed, the use of social media as a tool to influence policy and politics has become increasingly more prominent (Jansen *et al* 2009, Dubois and Gaffney 2014, Benthaus *et al* 2016, Jörgens *et al* 2018). The concretization of narratives and frames significantly impacts policy processes and key decision-making levers (Zhang *et al* 2015, Ghiassi *et al* 2016, Meire *et al* 2019)—particularly in the domain of climate change policy (Backstrand *et al* 2011, Fownes and Margolin 2018, Debnath *et al* 2023). Proposed socio-technical solutions in the digital town square are, consequently, subject to ongoing debates and conflicting perspectives (Kirilenko *et al* 2015, Müller-Hansen *et al* 2023).

Ours is not the first study to explore the influence of dominant frames on decarbonization transitions, including technological narratives surrounding CCS and hydrogen (Backstrand *et al* 2011, Torvanger and Meadowcroft 2011, Stephens *et al* 2011, Arranz 2016). Similar to this study, researchers have previously leveraged Twitter data to demonstrate how decarbonization technologies such as CCS and hydrogen are seen as the only viable solutions for industrial decarbonization (Otto and Gross 2021, Whitmarsh *et al* 2019).

Mander *et al* (2017), for example, investigate the framing of CCS as a crucial industrial decarbonization solution in Teesside—an industrial cluster in northeast England which is also covered by our study. Despite fervent online activity, they highlight that technical knowledge remains largely confined to a niche audience of industry and national policymakers— far removed from civil society and the broader 'Twitter Imagination' (Mander *et al* 2017). This insular knowledge, or CCS 'echo-chamber,' leaves the civil society largely on the sidelines of the debate. Constraints on the reach of these knowledge networks, in their view, preclude what otherwise might bring greater awareness of this 'critical technology' (Mander *et al* 2017). While the effectiveness of CCS in mitigating climate change continues to be debated (Scott *et al* 2013, Lane *et al* 2021)—a topic explored in section 3.3 below—Mander *et al* (2017) do open an important line of enquiry: how the 'Twitter Imagination' can shape the preferred technological solutions for industrial decarbonization.

More broadly, others explore Twitter's role in providing a forum for discussion of other climate change mitigation technologies beyond CCUS and hydrogen, such as renewable energy. For example, Mastroeni *et al* (2023) explore technological value propositions, the effect of the timing of tweets, and how 'communication strategies concerning sustainability in various contexts [...] change the behaviour of citizens through shared understanding' (Mastroeni *et al* 2023, p. 193). In a related study, using exploratory and machine-learning methods to analyse Twitter data, Mastroeni *et al* (2022) find that Twitter posts which are opposed to wind energy are amplified on weekends, and often originate from suspended or inactive accounts. This suggests that Twitter 'bots'—or fake profiles that troll real user's Tweets—are not only actively steering the wind energy narrative but are also strategic in the timing of these interventions. Mastroeni *et al* (2022) therefore bring awareness to narratives, contestation, and framing of low-carbon technologies, and the potential that detractors can have on climate technology solutions.

In a similar vein, Si *et al* (2023) show that the fossil fuel industry uses social media to impede the adoption of renewable energy technologies. Fownes and Margolin (2018) (2019) further illustrate how doubt is sown on Twitter, polarizing debates on crucial climate technologies and delaying climate policy actions—especially impacting those most affected by the transition. Similarly, Newman (2017) analyzes responses to the IPCC's fifth assessment report, finding that its urgent call to transition away from fossil fuels is contested by incumbent industry actors.

Despite these interventions, research connecting sustainability transitions and 'communication through social media is very limited' (Jha and Verma, 2023, p. 725). Specfically, there is a need for 'context sensitive research and independent social scientific studies that are not linked to the implementation ambitions of individual CCS projects' (Otto and Gross 2021, p. 10). In aggregate, though recent research sufficiently explores

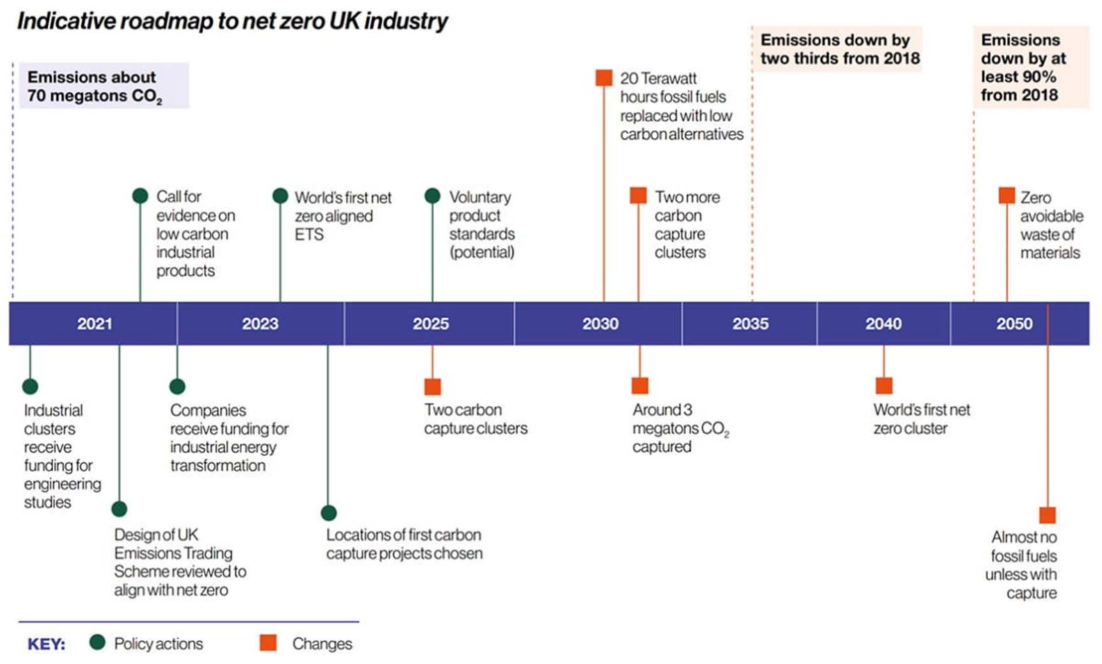

Figure 2. United Kingdom Government Timeline and Roadmap to Industrial Net Zero. Source: HM Government 2021: Industrial Decarbonisation Strategy (https://assets.publishing.service.gov.uk/media/6051cd04e90e07527f645f1e/Industrial_Decarbonisation_Strategy_March_2021.pdf).

the ways that technological adoptions can be influenced through social media narratives (Peng and Woodlock 2009), scant attention is paid to technological narratives germane to industrial decarbonization technologies, especially in industrial clusters. This matters because public engagement through social media platforms is particularly beneficial to industrial companies and technology suppliers that normally have 'no direct contact with end-consumers' (Wang *et al* 2021, p. 125).

These gaps underscore the need for further research into climate change and decarbonization narratives, particularly with respect to local actors and the embedding of technological narratives within industrial clusters. Indeed few studies examine the 'applications of social media to understand the social interest for sustainable practices between their users, Twitter in particular' (Mastroeni *et al* 2023, p. 194). It also calls for deeper investigation into the role of 'intermediary actors in transition' (Kivimaa *et al* 2019) and other powerful stakeholders to shape favorable technological prerogatives. In other words, 'how Twitter activity translates to offline outcomes' (Fownes Margolin 2018, p. 1). This forms a key motivation for our research. Segueing into this novel yet consequential body of emerging scholarship— especially considering important power dynamics that are driven through social media (Fownes and Margolin 2018)—we posit that the use of social media is pivotal to the framing, mythmaking, and storytelling about hoped-for technological solutions for industrial decarbonization.

3. Methods and conceptual approach

This section introduces our case study, research methods and data. It closes with a short discussion of the conceptual approaches germane to climate change narratives.

3.1. The United Kingdom's industrial decarbonization clusters

The UK is one of the most recent countries to undertake net-zero and decarbonization initiatives in its industrial sectors (*see* figure 2). Unlike many other nations, however, the UK has adopted a cluster approach, pitting geographic clusters in competition for significant public and private funding (Sovacool *et al* 2022, Herman *et al* 2024, Sovacool *et al* 2024d). The stakes are high. Indeed, beginning from billions of pounds of subsidies—including £1 billion for its Carbon Capture and Storage Infrastructure Fund, £240 million for the Industrial Decarbonization and Hydrogen Revenue Support scheme, and £315 million for its Industrial Energy Transformation Fund—government commitment has grown to include nearly £22 billion for CCUS alone (DESNZ 2023, DESNZ 2024). As shown in appendix table 1, indeed, the bulk of the initial cluster competition funding has been directed toward CCUS and hydrogen, particularly for transport and storage infrastructure investments.

Figure 3. The six industrial clusters in the UK. Source: BEIS: Industrial decarbonisation strategy (2021).

Table 1. Funding for each intermediary actor and cluster lead.

Actor	Funded by	Amount
Humber Plan	UK Gov; Growth deal programme	£1.7 million; £141.5 (Growth deal)
HyNet North west	UKRI; IDC (Industrial Decarbonisation Challenge)	£33 million (UKRI), £39 million (IDC)
NetZero Teesside	Oil and gas climate initiative (OGCI); *BP with Eni, Equinor, Shell and Total have assumed leadership, transitioning the Net Zero Teesside project from OGCI Climate Investments	£ unknown (OGCI); £52 million (ISCF)
ScottishClus ter	Innovate UK; Scottish Gov.; Industry (Capricorn, Harbour Energy, Crown Estate Scotland, Petroineos, SGN, Shell	£80 million (Scottish Gov-CCS)
SWIC Wales	UK Government; Industry	£1.5 million (4/2021); £20 million (3/2021); £18 million- industry (12/2020)

Sources: see footnote[4]

[4] https://www.humberlep.org/humber-cluster-plan-is-successful-in-1-7m-decarbonisation-funding-bid/ ; http://hynet.co.uk/wp-content/uploads/2021/03/032021-HyNet-IDC-award-press-release.pdf; https://www.gov.scot/news/scottish-cluster-support/ ; https://www.ogci.com/news/ogci-cis-first- investment-net-zero-teesside-selected-as-one-of-the-uks-first-two-carbon-capture-and-storage-hubs ; ISCF (UK gov) https://www.crunchbase.com/organization/net-zero-teesside/company_financials ; https://www.swic.cymru/news#:~:text=The%20South%20Wales%20Industrial%20Cluster,hydrogen%20 economy%20in%20South%20Walesb

The Industrial Decarbonisation Challenge ran from 2019 to 2024, led to the development of six cluster plans, nine deployment projects, and hundreds of industrial decarbonisation research projects (UKRI 2024). Each industrial cluster designated a 'cluster lead' responsible for drafting industrial decarbonization plans. Drawing from industrial cluster literature (Heidenreich and Mattes 2012, Zbuchea *et al* 2018), we define these cluster leads as intermediary agents, who are central to each industrial cluster's decarbonization transition in the five largest clusters. We elected not to analyze the Southampton and Black Country clusters as they were only recently added, and their GHG emissions are largely confined to a few industrial facilities. Figure 3 displays the clusters with their total GHG emissions, while table 1 outlines the relevant funding allocated to these intermediaries.

3.2. Data sources

We focus on the Tweets of intermediary agents who are detailed in table 1. Tweets, which are publicly posted microblogs, can raise situation awareness (Vieweg 2012), influence decision-making (Hennig-Thurau *et al*

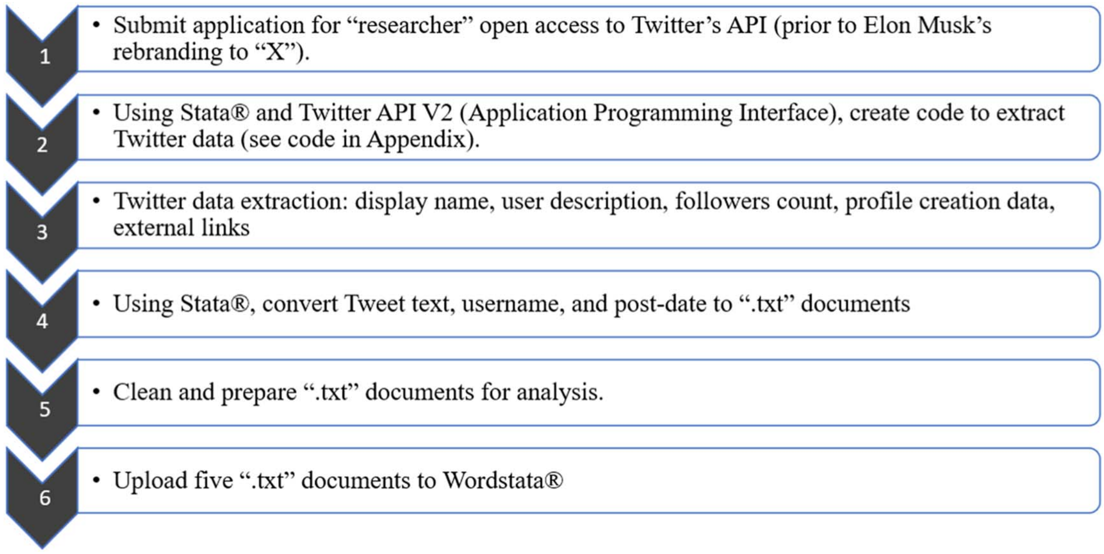

Figure 4. Data extraction procedure.

2015), build reputations and social capital (Wang *et al* 2021), and connect disparate knowledge networks (Ameripour *et al* 2010, Liu *et al* 2010, Qiu *et al* 2015). These data are also relevant to natural disaster management (Sovacool *et al* 2020), private-sector sustainability issues (Dawkins and Fraas 2011), as well as discussions around the circular economy and public discourse (Mastroeni *et al* 2022).

3.2.1. Data collection procedure

The data collection procedure was systematically carried out in five steps. First, we secured an API researcher license, granting us unrestricted access to the necessary data.[5] Next, we used an algorithm in Stata® to efficiently extract the Twitter data related to each intermediary actor. Data were then carefully cleaned, with a detailed list of data variables provided in appendix figure 1. After data extraction and cleaning, we converted the datasets into text documents to prepare them for machine-aided content analyses using Wordstat®. For an overview of the basic handle data for each intermediary actor, refer to table 2 and appendix table 1.

3.2.2. Data analysis procedure

After preparing and uploading our data into Wordstat®, we initiated the analysis procedure (figure 5). We then applied standardization techniques, such as the elimination of erroneous words, truncating text, and removing special characters and symbols. Next, we executed automated keyword extraction, following the guideline outlined in the Provalis instruction document (Provalis Research 2021). With the automated results at hand, we proceeded with keyword clustering and link analyses.

Once the automated procedures and results were completed, we moved to semi-automated analysis using a dedicated dictionary specifically designed for our topic (Blei 2012) (see appendix figure 1). Utilizing this categorization model and dictionary, we conducted semi- automated keyword analysis, filtering out keywords according to Term Frequency-Inverse Document (TF*IDF) score below 2. A higher TF*IDF demonstrates the uniqueness of keywords in comparison to the corpus (Qaiser and Ali 2018, Provalis Research 2021).

One limitation of the TF*IDF algorithm is that sometimes it has difficulty to disaggregate words with somewhat small variations; for instance, it treats 'play' and 'playing', 'mark' and 'marking', as well as 'year' and 'years' as distinct words' (Qaiser and Ali 2018: 29). We sought to ameliorate this limitation by carrying out final checks by hand. Furthermore, shortly after Elon Musk's acquisition of Twitter, it was no longer possible to obtain a free, open access API. Due to this restriction, we could only assess the Tweets of intermediary actors up to the end of February 2023. It is, however, possible to extend our analysis using a newly unveiled pay service for API—though this paywall will reduce the replicability of our study.

[5] The common method for obtaining such data involves acquiring an API (Application Programming Interface) key and extracting data like Tweets and total user followers is the common method (Lantian *et al* 2016). After obtaining API 'researcher' open access, we were able to extract data up to February 2023, when access became restricted by a paywall. Until shortly after the Elon Musk's acquisition of Twitter, researchers had open access to data via an API V2. In line with the methods used by Jones *et al* (2016), and Si *et al* (2023), we then used the Stata API interface to code, extract and clean the data.

Table 2. Basic twitter data on each of the five intermediary actors.

Screen name	Display name	User description	Followers	Profile create year	URL
Humber Plan	The Humber Industrial Cluster Plan	The HICP is a project funded by Innovate UK, led by CATCH, the Humber LEP and 8 industrial partners to reach net zero by 2040	361	Jan., 2021	https://www.humberin dustrialclusterplan.org/
HyNet	HyNetNW	A 'game changing' hydrogen & CCS energy project, decarbonising the NorthWest & NorthWales. Aiming to be the UK's first netzero carbon industrial cluster.	1229	Dec., 2020	https://hynet.co.uk/
NetZero Teesside	Net Zero Teesside	NZT is part of the East Coast Cluster and represents the vision to decarbonise industry using CCUS on Teesside, serviced by the Northern Endurance Partnership.	1204	Sept., 2019	https://t.co/fyHFnSN8 B3
Scottish Cluster	Scottish Cluster	The Scottish Cluster brings together industry, academia, communities, policy makers and regulators to work together to make a net zero Scotland and UK a reality	506	July, 2021	https://t.co/K883QbrN OT
SWIC Wales	SWIC South Wales Industrial Cluster	Developing a world leading truly sustainable cluster befitting the societal needs of 2030,40,50 and beyond. From the Pembrokeshire Coast to the Severn Bridge.	419	April, 2020	https://www.swic.cym ru/

Source: Twitter handle basic data.

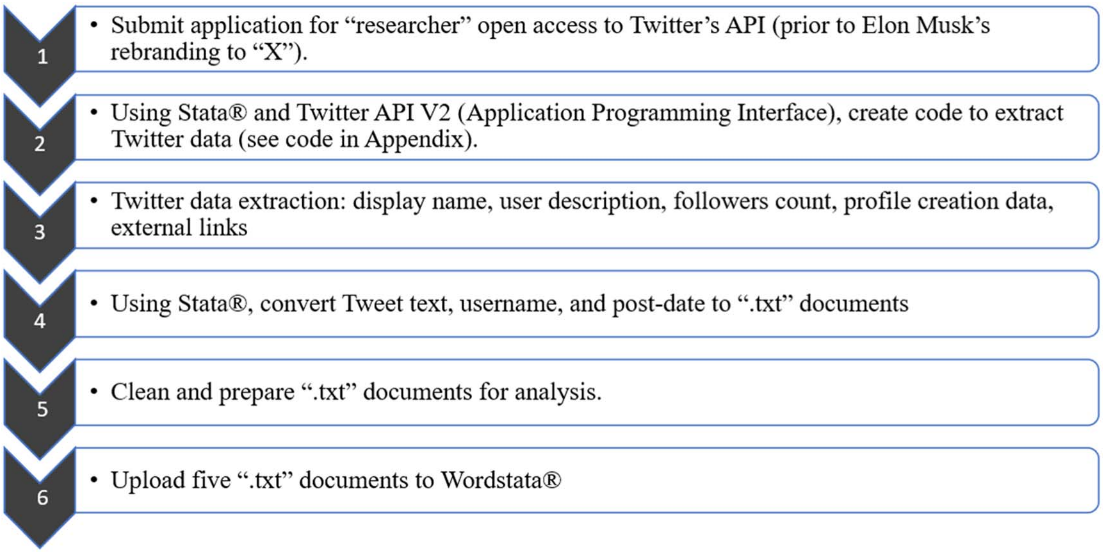

Figure 5. Data analysis procedure and alogirthm to utilize the original Twitter data.

3.3. Conceptual approach of climate change narratives

Before presenting the results in section 4, we briefly examine climate change narratives and value propositions for decarbonization technologies, highlighting their influence on policy decisions—a well-established area of research (Smith *et al* 2010, Karnøe *et al* 2022, Stefani *et al* 2022, Sovacool *et al* 2022). Understanding why certain actors are more effective in this domain is essential (Bruns and Moe 2014). As Labonte and Rowlands inquire, 'What narratives, ideas, and frames are deployed on social media regarding sustainability transitions, and what do they reveal about broader public discourse?' (Labonte and Rowlands 2021, p. 1).

Within sustainable transitions, technological frames often connect to specific problems a technology can address and its associated value propositions (Sovacool *et al* 2023b, p. 8). Actors promoting particular technological narratives seek legitimacy through various framing strategies (Castelló and Lozano 2011). The value propositions shared on social media significantly impact organizational strategy and innovation (Suseno *et al* 2018). Research in this area typically examines the adaptation and adoption of narratives over time (Shanahan 2017, Bain and Chanban 2017, Stefani *et al* 2022).

Solutions for mitigating climate change differ widely in cost, complexity, location, and expected outcomes (Bain and Chaban 2017). The prioritization of certain technologies over others can significantly influence the speed and quantity of both private and public sector investment decisions, particularly in areas such as infrastructure, R&D, innovation, and technology demonstration. As the proposed solutions for achieving 'net zero' begin to be implemented, some technologies are likely to gain broader acceptance because they directly address the 'net' aspect of the 'zero' GHG goal (Turner *et al* 2021). Nevertheless, since there are limited time and funds available to respond to climate change—and different actors hold different perspectives and motivations —technological contestation arises (Bauer *et al* 2017, Ringel *et al* 2021).

Contention intensifies when competition for funding arises (Rosenberger *et al* 2017, Richardson *et al* 2016, Jha and Verma 2022). The rate at which narratives evolve influences the allocation of public and private funding, particularly for preferred technological solutions to climate change (Shanahan 2017, Wemyss *et al* 2023). Understanding why certain actors excel in this domain is crucial (Bruns and Moe 2014). As Labonte and Rowlands ask, 'What narratives, ideas, and frames are deployed on these new [social media] platforms, and what do they reveal about broader public discourse on sustainability transitions?' (Labonte and Rowlands 2021, p. 1).

The industrial decarbonization transition has catalyzed much debate, with actors disagreeing on the most suitable and economically viable technologies (Mathur *et al* 2022, Devine-Wright 2022, AbdulRafiu *et al* 2022). Hydrogen technologies, for instance, have resurfaced as a potential decarbonization solution for industry, despite previous setbacks (Bakker 2010, Bakker and Budde 2012, Yap and McLellan 2023). Indeed, 96% of global hydrogen production currently relies on fossil fuels (Howarth and Jacobson 2021). For hydrogen to be a viable decarbonization option, it must be produced from renewable or nuclear energy, or methane combined with CCUS (Howarth and Jacobson 2021). In addition, while CCS has faced criticism for its poor track record (Gonzalez *et al* 2021), UK experts argue that 'CCS is a necessity, not an option' (CCC 2019, Plaza *et al* 2020). This contrasts with the IPCC's assessment that CCS is merely an option for reducing emissions if geological storage is available (IPCC 2023, p. 86). Since CCS/CCUS reinforces existing energy systems and their stakeholders

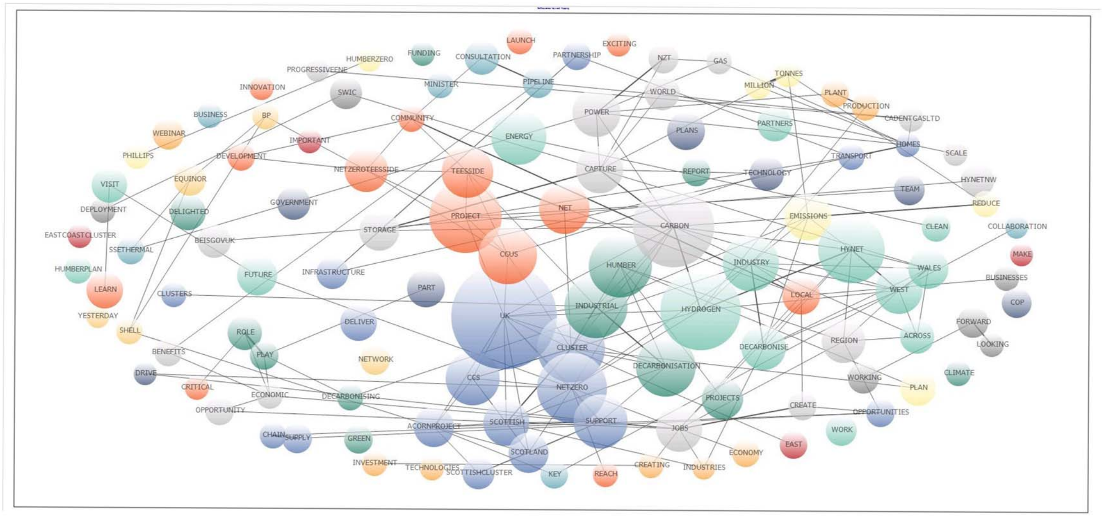

Figure 6. Automated cluster mapping and link analyses. Settings: same paragraph, Jaccard's coefficient, word co-occurrence-first order, tolerance = .000001, maximum iterations = 500, 40 clusters.

(Goldstein *et al* 2023), the oil and gas industry in the UK largely supports these technologies (Oil and Gas UK 2020). Trade organizations like One Northeast and NECCUS also endorse this perspective. Conversely, civil society organizations express skepticism about CCS's potential to address climate change, citing distrust in the oil and gas sector's decarbonization efforts and the limited results from prior funding (Gonzalez *et al* 2021, p. 2). They view CCS as a tool for the oil and gas industry to 'offset and justify new exploration' (Gonzalez *et al* 2021). We will revisit these arguments in the Discussion and Conclusion sections.

4. Results: six emergent themes

This section presents the results of the automated extraction conducted using Wordstat® (Section 4.1) and the subsequent semi-automated extraction using the custom keyword dictionary (Section 4.2) (Appendix figure 1). In this research context, we hypothesize that intermediary actors play a crucial role in influencing the framing of technological solutions for climate change, similar to Suseno *et al* (2018). Our findings largely confirm the prominent narratives and framing surrounding industrial decarbonization, particularly through the analysis of the Twitter posts from these intermediary actors (see figures 6 and 7).

The automated text analysis led to the identification of six core themes: (1) CCS/CCUS; (2) Hydrogen; (3) Jobs and Economy; (4) Infrastructure; (5) Collaboration and Clusters; (6) GHG Emissions. We briefly outline what these themes mean in the UK's case, before turning to a discussion of the findings in the next section. For further details, see appendix tables 4.1.1–4.2.3.

The first theme is CCS/CCUS, a key element of the UK's industrial decarbonisation strategy (Sovacool *et al* 2024a). The UK's 2018 CCS Action Plan emphasized a cluster-based approach, setting targets for the first CCUS facility by the mid-2020s and expanded deployment in the 2030s. Government views CCS/CCUS as essential for mitigating emissions in 'hard-to-abate' sectors, including petrochemicals, iron and steel, cement, pulp and paper, glass and ceramics, and food processing (Harvey *et al* 2023). Additionally, it holds potential for integration with Sustainable Aviation Fuel (SAF) and BECCS technologies (Michaga *et al* 2022, Herman and Sovacool 2024).

The second theme is Hydrogen, which under specific conditions can significantly reduce emissions compared to conventional energy sources like natural gas and grid electricity (Ueckerdt *et al* 2024). Decarbonizing industries such as chemicals and steel through electrification presents challenges, but hydrogen combustion for high-temperature processes is a promising solution (Griffiths *et al* 2021). Blue hydrogen is considered to be particularly well-suited for UK industrial clusters with limited alternatives (Pultar and Ferrier 2022). Additionally, the development of hydrogen clusters is expected to create economies of scale for shared infrastructure, aligning with the UK's potential for hydrogen storage (Jahanbakhsh *et al* 2024).

The third theme is Jobs and Economy. A main concern is that ambitious industrial decarbonization targets may be hindered by a shortage of skilled workers (PWC 2022). Achieving the required infrastructure across pre-construction, construction, and operation phases will demand a workforce of approximately 350,000 (UKRI 2023). While around 9 million individuals currently possess the skills to support industrial

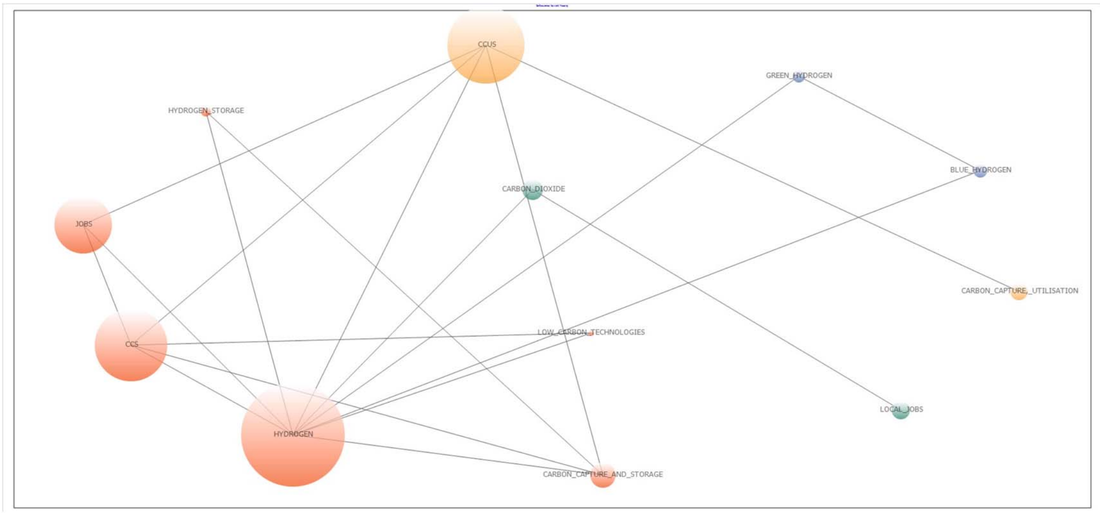

Figure 7. Semi-Automated cluster mapping and link analyses. Settings: keyword linking with Jaccard's coefficient, same paragraph, after exclusion of keywords with TF*IDF less than 2.0.

decarbonization, they are already stretched across various sectors (Simpson and Howe, 2022). Structural economic changes, combined with a decline in workers with the necessary expertise, have exacerbated the skills gap (Vona *et al* 2018, PWC 2022, UKRI 2023). Additionally, approximately one million individuals in higher education could help address this gap through relevant courses and apprenticeships (HM Government 2021).

The fourth overarching theme is Infrastructure. The UK's *Industrial Decarbonization Strategy* (HM Government 2021) sets key goals, including connecting four major industrial clusters to decarbonization infrastructure by 2030. The explicit goal is to capture at least 3 million tons of CO_2-equivalent emissions—comparable to planting 500 million trees. In addition to these targets, four strategic principles guide the decarbonization strategy: *alignment* (ensuring net-zero goals integrate with other objectives like clean growth and leveling up), *effectiveness* (holding industry accountable for necessary actions), *proportionality* (sharing responsibility between government and industry), and *flexibility* (adapting to technological, societal, and market changes).

The fifth theme is Collaboration and Clusters. As mentioned in the introduction, UK government has a goal to establish one low-carbon cluster by 2035 and at least one net-zero cluster by 2040 (HM Government 2021). In addition, it Industrial Decarbonization Cluster competition has pitted geographic clusters in competition against one another for significant public and private funding (Sovacool *et al* 2024d). There is, thus, a tension between competition and collaboration. The interaction between centralized clusters and dispersed industrial sites necessitates tailored strategies that account for the diversity of industrial landscapes; as Lai *et al* (2024: 3) state, 'technology deployment is a place-making process that impacts host communities and shapes sense of place.' Using a critical stakeholder analysis, Lai and Devine-Wright (2024) examined place-based perceptions in three clusters—Northwest, South Wales, and Scotland—revealing a complex set of values and beliefs held by stakeholders regarding each cluster.

The final theme is GHG Emissions. To reiterate, GHGs in industrial sectors are significant, as they account for nearly one quarter of global CO_2 emissions from energy systems (IEA, 2023), and policies should prioritize technological innovation within industrial clusters to address the decarbonization challenge (WEF 2023). Industrial decarbonization initiatives can significantly reduce the carbon footprint of hard-to-abate industrial processes, serving as a critical measure against climate change and contributing to global environmental sustainability (Ogwumike *et al* 2024). Furthermore, addressing conflicts between free trade regulations and deep decarbonization policies is essential for promoting effective international cooperation (Griffiths *et al* 2021, Ogwumike *et al* 2024).

5. Discussion: decarbonization narratives in comparison

In this section, we discuss the findings in relation to existing literature, focusing on results with TF*IDF scores above 2.0. These results include prominent themes that were identified through topic extraction, key terms from keyword mapping, and significant connections found in the link analyses.

As discussed in section 2, research underscores the critical importance of ensuring that net-zero pathways are both socially acceptable and legitimate to prevent potential backlash from civil society (Turner *et al* 2021, Gough and Mander 2022). In this vein, a more coherent understanding of power dynamics within social platforms—and how these can shape climate change narratives—is called for, especially pertaining to technologies favored by incumbent actors (Sovacool *et al* 2023a). Our findings indicate that intermediary actors generally hold the view that CCUS and hydrogen are vital components to achieve net-zero within industrial clusters, which also aligns to central government policies on industrial decarbonization.

The alignment of intermediaries with incumbent industry is not surprising given the substantial funding offered by the UK government and the primary source of funding sources for intermediary actors (e.g., table 1 above). Net Zero Teesside, indeed, described CCUS as 'a game changer' in the fight against climate change. In addition, the Scottish Cluster argued that CCUS 'is key to ensuring that the oil & gas sector in the North East of Scotland can play its part in reducing Scottish & UK emissions and reach #netzero.' Though these claims echoe those of the Climate Change Committee, that 'CCS is a necessity not an option (CCC, 2019)—they run counter to the IPCC's specification that 'CCS is an option to reduce emissions from large-scale fossil-based energy and industry.'

The positive sentiment surrounding these two technology vectors (CCUS and hydrogen) extends to another recurring theme promoted by cluster intermediaries: jobs and economic growth. These themes are central to recent arguments supporting green industrial transitions and the notion of win-wins (Meckling 2021, Sovacool *et al* 2024a). For example, each of the five intermediary actors frequently highlighted that the development of CO2 and hydrogen pipeline infrastructure would lead to job creation and local economic impacts.

Although the emphasis on employment fits the green industrial transition narrative that public funds are needed to stimulate local economies, the assumptions and methodologies behind these job's claims are often opaque and overly-optimistic. For instance, the East Coast Cluster anticipates creating 12,300 indirect jobs per year during construction phases, while HyNet expects 6,000 direct jobs and up to 75,000 indirect jobs 'across the UK.' In similar vein, the Humber Cluster promoted the idea that 'The V Net Zero pipeline will secure jobs & skills training in the Humber region, whilst also helping the environment.' Similarly, Net Zero Teesside claims that, once operational, it will create 5,500 direct jobs over the next five years. Nevertheless, these job's estimates are highly uncertain, especially considering that many of these projects are 'first-of-a-kind,' and have never been done in the UK (Geels *et al* 2023, Hudson and Lockwood 2023).

Infrastructure is another major theme closely tied to job creation, as thousands of well-paying jobs are expected during infrastructure build-out. It is expected that the HyNet CO2 pipeline will be the first to be completed in the UK. HyNet Northwest stated that 'HyNet is already underway in establishing the infrastructure needed to decarbonize the North West of the UK. ' In a later Tweet, it welcomed the UK government's proposed 'business models for wider hydrogen transport and storage infrastructure;' and it also stated that 'HyNet is already underway in establishing the infrastructure needed to decarbonise the North West of the UK through CCUS and low-carbon Hydrogen.' From a similar perspective, HyNet Northwest expected that, in its first phase, 'our CO2 pipeline will help support thousands of jobs in the #NorthWest & #NorthWales. Help us realise these benefits by having your say.'

The uncertain future of many projects challenges the claim of lasting economic benefits. Most construction jobs are temporary, posing the risk of limited long-term local economic impact (Sovacool *et al* 2024). Furthermore, although framed as 'net-zero' infrastructure, a critical view suggests that pipeline infrastructure jobs primarily support oil and gas industry. The rationale behind these policies is therefore subject to ongoing debate with concerns that incumbent firms—particularly in the oil and gas sector—are to receive the bulk of initial funding to clean up a mess that they created (Rattle and Taylor 2023). Estimates of infrastructure-related jobs are, moreover, difficult to verify due to the UK's limited experience with industrial decarbonization infrastructure and its mixed track record in delivering publicly funded megaprojects across sectors (Geels *et al* 2023, Sovacool *et al* 2023b).

The potential for collaboration and experimentation within clusters emerged as a key theme, and also offers a promising area for future research. Successful collaborations could drive innovation and technological diversification, potentially reducing reliance on dominant technologies like CCS and hydrogen (Sovacool *et al* 2022, Herman *et al* 2024). For example, Net Zero Teesside emphasized the industry's willingness to collaborate to accelerate a range of low-carbon technology innovation and implementation, and South Wales close-connection to research institutes. On the other hand, a lack of collaboration, both within and across clusters, could hinder innovation, leading to the failure of net-zero initiatives and reinforcing technological monopolies dominated by powerful oil and gas firms (Sovacool *et al* 2024a).

Emissions emerged as a central, albeit expected, topic given the primacy of achieving net-zero GHG emissions by mid-century. Notably, intermediaries made bold claims about the substantial and near-immediate potential for emissions reductions, with the benefits of net-zero mentioned 368 times, often in reference to CCUS. For example, Net Zero Teesside asserted that 'CCUS provides the solution needed to capture emissions at their source and lock them in,' and described it as 'a critical technology for achieving the UK Government's net-zero target by 2050.' Similarly, the Scottish Cluster emphasized that '#carboncapture & storage reduces emissions from hard-to-decarbonize sectors like manufacturing.' Meanwhile, SWIC expanded on this argument to include local health benefits, stating that decarbonizing industry would 'minimize air pollution and reduce carbon emissions—vital for protecting children's health.'

Intermediary actor narratives surrounding net-zero emissions closely align with those of incumbent industries and firms. For example, Net Zero Teesside highlighted the role of major oil and gas companies, tweeting that the 'Kickstarter initiative brings together world-class industry expertise and five OGCI members—@bp_plc, @eni, @Equinor, @Shell, and @Total.' The uncertain development of CCUS challenges these claims, however, particularly since the UK still lacks a commercial-scale carbon capture and storage project (Stephens *et al* 2011, Müller-Hansen *et al* 2023), and CCUS projects in more advanced industrial clusters abroad have already faced considerable delays or closures (Torvanger and Meadowcroft 2011, Arranz 2016, Buck 2021, Hudson and Lockwood 2023).

6. Conclusion

This article examined the narratives and frames surrounding industrial decarbonization clusters in the UK using Twitter (now X) data. Given the platform's role in fostering discussions on climate and technological issues, we analyzed key themes related to industrial clusters, which are set to receive billions of pounds in public funding for technological and infrastructural progress toward net-zero. Our focus was on the main intermediary actors within the five largest industrial clusters, defined by their total GHG emissions.

We contributed conceptually and empirically to this growing field of research. Conceptually, we traced the technological and economic narratives of intermediary actors using a unique social media dataset. Empirically, our analysis uncovered surprising consistency in the technological frames and expectations of intermediary actors, particularly regarding future economic growth driven by net-zero infrastructure and technologies. We provided evidence that these narratives closely align with those of incumbent industries, with intermediary actors promoting CCUS and hydrogen as the primary solutions for net-zero in heavy industry—and continually emphasizing both climate and economic benefits. Additionally, we identified two influential intermediaries—Net Zero Teesside and the Scottish Cluster—as shaping much of the discourse in the digital town square.

In conclusion, this analysis highlights the contested technological framing processes in industrial decarbonization as public funding becomes available and government policies align predominantly with the interests of incumbent industries. However, civil society appears largely excluded from this discourse. This finding underscores the necessity for more open debate and increased transparency in job estimation methodologies and associated economic benefits. Additionally, it raises concerns about the prudence of infrastructure-centric industrial decarbonization policies, particularly given the likelihood of civil society backlash as legacy oil and gas firms receive substantial grants and subsidies.

As narratives evolve, the uncertainties surrounding the emissions reduction potential of industrial decarbonization technologies will further complicate the net-zero transition. On a positive note, intermediary actors are fostering collaborative approaches by bringing together firms, researchers, government, and investors. Should alternative technological vectors beyond CCUS and hydrogen be discussed more openly, there could be a greater role for broader experimentation and innovation. Conversely, if intermediary actors focus predominantly on promoting CCUS and hydrogen, the potential for developing more innovative industrial decarbonization technologies may be diminished.

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Data availability statement

Data files can be requested subject to "X" guidelines. The data that support the findings of this study are available upon reasonable request from the authors.

Disclosure statement

During the preparation of this work the authors used Twitter's Open API to obtain data. After using this tool/ service, the authors reviewed and edited the content as needed and take personal responsibility for the content of the publication.

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