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Accelerating sustainability transitions: the case of the hydrogen agenda in the North West region of England

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ABSTRACT

Low-carbon hydrogen can assist in addressing the global crisis of climate change by significantly decarbonizing a range of heavy-emitting sectors. In the United Kingdom, hydrogen technologies are at the forefront of the net zero-emission roadmaps of many industrial clusters. However, with impending timeframes linked to emission targets and other decarbonization objectives, it is increasingly important to understand how to accelerate such transitions to hydrogen. There is, to date, a notable gap in the academic literature concerning the acceleration of sustainability transitions. Using the case of the hydrogen agenda in England's North West region, we explore how the transition to hydrogen can be accelerated and thus begin to contribute toward filling this omission. In doing so, we use data collected through semi-structured interviews and from the public domain to unpack and develop upon an existing framework that emerged from the European Commission funded-project Accelerating and Rescaling Transitions to Sustainability (ARTS). The framework comprises five acceleration mechanisms which local sustainability transition initiatives have adopted. This analysis generates novel findings in relation to why actors in the region have faced difficulties in instrumentalizing as well as the mechanism's overall importance in acceleration. We use these challenges to inform several recommendations which policy makers could adopt to accelerate the North West's, and wider UK's, transition to hydrogen.

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Introduction

In 2020, global energy-related carbon-dioxide emissions (CO_2) exhibited a 5.8% decline from the previous year as a result of the COVID-19 pandemic (IEA 2021b) and this was the largest reduction since World War II (McSweeney and Tandon 2020). Despite this decrease, the global concentration of CO_2 continued to climb and reached 412.5 parts per million (ppm) in 2020 – a new yet devastating record (NOAA 2021). In addition, the International Energy Agency (IEA) alarmingly projects that energy-related CO_2 emissions will increase by 4.8% in 2021 as the economy rebounds (IEA 2021a). To limit global warming to well below 2°C as stipulated in the Paris Agreement, global greenhouse gas (GHG) emissions must peak, and decline, as soon as possible (UN 2015). This truly signifies the importance of monumental decarbonization on a rapid timescale.

Correspondingly, many countries have published COVID-19 recovery plans with decarbonization policy at the forefront. In the European Union's (EU) recovery plan, 30% of total funds available were allocated toward fighting climate change – the highest share of the budget to date (European Commission 2021). Additionally, the UK government published its "Ten Point Plan for a Green Industrial Revolution" which pledges support for an array of low-carbon technologies (Her Majesty's Government 2020). One of the plan's core objectives is to drive the growth of low-carbon hydrogen by supporting the development of 5-gigawatts (GW) of hydrogen-production capacity by 2030 through a £240 million "Net Zero Hydrogen Fund."

With net-zero end-use emissions, hydrogen can significantly decarbonize numerous heavy-emitting sectors (Blanco et al. 2018). According to National Grid's Future Energy Scenarios, hydrogen could supply up to 21–59% of the UK's end-user energy needs by 2050 (National Grid 2020). To deliver on this objective, and net-zero emission targets (Her Majesty's Government 2019), low-carbon hydrogen production with carbon capture and storage technology must be deployed within the next decade. The Industrial Decarbonization Challenge (IDC) supports the development of net-zero industrial

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clusters and seeks to establish at least one low-carbon cluster by 2030 as well as the world's first net-zero industrial cluster by 2040 (UKRI 2021a). The North West cluster encompasses the largest concentration of advanced manufacturing and chemical production in the UK with approximately 6 million tonnes of CO_2 emitted each year (Net Zero North West 2020). The magnitude of these releases places the region in a unique position to benefit from the establishment of a hydrogen network.

Socio-technical transitions studies can shed light on how such transformations to hydrogen can occur by analyzing the dynamics between new technologies, changes in markets, user practices, infrastructure, and policy (Bulkeley et al. 2011). Typically, such transitions emerge over decades (Loorbach, Frantzeskaki, and Avelino 2017), but given the urgency to decarbonize in accordance with a rapid timeframe, there is a need to better understand how transitions can be deliberately accelerated (Köhler et al. 2019; Markard, Geels, and Raven 2020).

Recent research has begun to explore this topic (Markard and Hoffmann 2016; Roberts and Geels 2019; Sovacool 2016; Kern and Rogge 2016; Durrant et al. 2018; Ehnert et al. 2018; Markard, Geels, and Raven 2020).[1] However, there is still a notable gap concerning the acceleration of sustainability transitions toward a hydrogen economy. Throughout this article, we therefore seek to contribute to this emerging body of literature by exploring how the transition to hydrogen in England's North West region could be accelerated. In doing so, we analyze a portfolio of hydrogen initiatives across the region by unpacking the acceleration mechanisms framework developed by the Accelerating and Rescaling Transition to Sustainability (ARTS) project (Frantzeskaki et al. 2017; Durrant et al. 2018; ARTS 2021). As we describe, the analysis generates novel observations that assist in enhancing the current understanding of acceleration mechanisms.

The remainder of this article is comprised of five further sections. First, we provide an overview of the literature which has inspired this research. This discussion leads to the establishment of the specific research questions we seek to address. Second, we explain our methodology and research methods. Third, the results section highlights examples of each acceleration mechanism exhibited by hydrogen initiatives in the region. Fourth, the discussion section unveils novel observations regarding the importance of instrumentalization and how this may actively support other acceleration mechanisms. This fosters broader consideration of why some transition initiatives struggle to instrumentalize in the fifth section. Building on this framework, we borrow concepts from the wider body of literature surrounding the acceleration of transitions and use them to propose intervention strategies which policy makers could adopt to ensure the acceleration of hydrogen-transition initiatives in the region and the wider UK. Finally, our conclusion details how this study has contributed to a more generalized understanding of the acceleration of sustainability transitions.

Accelerating sustainability transitions

Sustainability transitions are conceptualized as large-scale societal changes required to solve "grand societal challenges" (Loorbach, Frantzeskaki, and Avelino 2017). The term transition refers to the shift from one socio-technical system to another and exhibits the following characteristics: multiple changes in socio-technical configurations, development of technical innovations, and multi-actor processes that entail interactions between social groups (Geels and Schot 2010). Typically, transitions occur over a 40–50-year period. However, Markard, Geels, and Raven (2020) argue that emerging innovations as part of on-going sustainability transitions must be accelerated in order to address the urgency of grand sustainability challenges. When publishing an updated research agenda for the wider field of sustainability transitions studies, this view was mirrored by Köhler et al. (2019) who identified the need for future research to explore the speed of transitions and how they could be accelerated Köhler et al. (2019, 6).

Upon reviewing literature concerned with the timescales of energy transitions, Sovacool (2016) provided evidence of ten case studies where energy transitions took only 1–16 years to unfold. Subsequently, Sovacool (2016, 203) argued that energy transitions could occur "much more quickly than commonly believed." In response to this contention, Grubler, Wilson, and Nemet (2016, 24) highlighted the need to evolve this discussion from "How long does it take?" to "What does it take?" Additionally, Kern and Rogge (2016, 16) argued that Sovacool's claim did not sufficiently emphasize the importance of the role of "political will" and contended that commitment from all levels of governance lies at the heart of the pace of low-carbon transitions. Kern and Rogge (2016) therefore identified the need to discuss the varying roles that actors must play to ensure an unfolding of more rapid transitions.

Contributing further to this debate, Roberts and Geels (2019) investigated intervention strategies that could deliberately encourage the breakthrough of socio-technical systems from initial niche markets. The findings of this research were based on a

Table 1. Intervention strategies that policy makers could adopt to deliberately accelerate transitions.

	Classic Steering (Top-Down)	Market Model (Bottom-Up)	Interactive Network Governance
Social Relationships	Government responsible for steering markets and society	Policy makers have "arms-length" relations with firms and societal actors which are relatively independent	Mutually dependent interactions between policy makers, firms, and societal actors
Government Roles	Government sets goals, selects solutions, and shapes implementation through law	Policy makers articulate goals and shape framework conditions but let autonomous actors choose solutions	Policy makers moderate, orchestrate, and facilitate learning processes and information exchange aimed at defining problems and exploring solutions
Policy Instruments	Regulations, laws, standards, state-led investment programs	Subsidies, taxes, and fiscal incentives	Roundtables, public-private partnerships, demonstration projects, public debates, and experiments

Source: Adapted from Roberts and Geels (2019).

comparative analysis of two historical case studies in Dutch and Danish heating and enriched with previous research concerning various policy approaches (Geels et al. 2015). The "conditions for intervention" were expressed in terms of structural and proximate social conditions. In relation to the former, examples listed included the absence or weakness of an incumbent regime; the existence of a proven, well-developed niche; and the presence of focusing events that favored moving away from the status quo. For the latter, positive conditions included a lack of user opposition, a united front between policy makers and business actors, and a preference for policies that enhanced public acceptability. The intervention strategies proposed by Roberts and Geels (2019) are outlined in Table 1 and will be revisited again later in this article.

Geels et al. (2019) recognize cities and regions as playing an important role in sustainability transitions as they provide valuable opportunities for learning and offer the possibility of achieving whole system change at local scales. At the city-region level, transition scholars have investigated the way in which transition initiatives (TIs) can accelerate sustainability transitions as part of the ARTS project (ARTS 2021). This research is particularly timely given the proliferating number of sustainability initiatives in cities (Gorissen et al. 2018). Throughout the duration of this project, an interesting body of literature surrounding the acceleration of local sustainability transition initiatives has emerged. One of the key outcomes from this project has been development of a novel framework that conceptualizes the following five acceleration mechanisms: upscaling, replicating, partnering, instrumentalizing, and embedding (Frantzeskaki et al. 2017).

First, upscaling consists of the growth of members, supporters, or users of a TI to spread new ways of thinking, organizing, and practicing (Frantzeskaki et al. 2017). This mechanism can have a positive impact on acceleration as it can induce spillover effects that inspire wider changes in society (Ehnert et al. 2018). Furthermore, as a result of upscaling, TIs can receive increased visibility from political actors, which could influence political agenda-setting. In terms of specific strategies adopted, scholars have identified the occurrence of upscaling through numerous activities such as project development, marketing, raising awareness, and developing partnerships (Durrant et al. 2018). Most commonly, evidence of upscaling is reported throughout the literature in relation to the growth of members of a transition initiative.

Second, replicating refers to adoption of new ways of doing, organizing, and thinking from one TI by another (Frantzeskaki et al. 2017). This process can occur via three dimensions: inward replication, internal replication, and external replication. In research conducted by Gorissen et al. (2018), it was found that eight out of ten empirical examples of replicating showed evidence of inward replication. In contrast, the authors only identified four instances of internal replication and one example of outward replication. In a similar vein, in their comparative case study, Ehnert et al. (2018) identified that there was little evidence of internal replication occurring across the numerous city-regions that they explored. Overall, Durrant et al. (2018) characterized two forms of replication: the replication of sustainable practices and the replication of strategy. Within the domain of energy, evidence of replication involved the importing of ideas and practices from outside the city-region (an example of inward replication).

Third, partnering as a mechanism describes how TIs can pool resources and competences in order to exploit synergies (Durrant et al. 2018). This phenomenon has been shown to occur both between TIs as well as between TIs and other organizations (either inside or outside of the city-region). However, it is important to note that partnering across sectors often proved to be particularly challenging due to various actors speaking "different languages" (Ehnert et al. 2018). To elaborate, Ehnert et al. (2018) identify that actors from the public sector, private sector, and civil society pursue different, and possibly conflicting, interests. Commonly cited activities attributable to this mechanism include informal meetings, strategic alliance building, joint events, and information sharing (Durrant et al.

2018). In terms of impact on acceleration, partnering can result in knowledge sharing, resource sharing, and showcasing sustainability solutions (Gorissen et al. 2018). Accordingly, these processes can assist in the diffusion of more sustainable ways of thinking and practicing into the wider public.

Fourth, Gorissen et al. (2018) report that there are two forms of instrumentalizing that are vital: mobilizing resources and capitalizing opportunities. The former describes a TIs ability to draw upon multiple sources of assistance made available from external actors. The latter refers to a TIs ability to use global trends as an entry point for "getting the ball rolling" locally. In relation to the initiatives studied by Durrant et al. (2018), the most common types of instrumentalizing include the exploitation of policies and/or the establishment of funding schemes to secure financial support for the development of projects. For example, one initiative relied on feed-in tariffs to create a viable solar photovoltaic (PV) business model. Ehnert et al. (2018) identify the mobilization of such resources as a core skill for TIs to advance sustainability locally.

Finally, embedding involves the alignment of old and new ways of doing, thinking, and organizing within city-regional governance patterns (Frantzeskaki et al. 2017). In the studies conducted as part of the ARTS project, embedding occurred in the following two ways: routinization and institutionalization. On one hand, the former relates to the embedding of more sustainable ways into the daily routines of actors involved in the TIs (Gorissen et al. 2018). Institutionalization, on the other hand, relates to the embedding of sustainable practices within existing or new institutions (Durrant et al. 2018). Previous research has identified that government actors assume various roles including as initiators, collaborators, and supporters (Gorissen et al. 2018). Embedding proved to be easier if incumbents and TIs perceived a synergy between the objectives and activities they pursued (Ehnert et al. 2018). This could be a resource synergy, a governance and institutional synergy, and/or a social synergy.

Since the initial conceptualization of these five acceleration mechanisms, subsequent research has since enhanced the framework. For example, the initial formulation presented each mechanism as separate and distinct. While investigating eleven TIs across numerous domains in the city of Brighton and Hove, Durrant et al. (2018) were able to identify novel findings relating to the mutual influence of different acceleration mechanisms. They found that activities ascribed to one particular mechanism, in most instances, were found to play a supporting role in activities attributed to another. These dynamics are briefly outlined in the fourth column of Table 2 and will be revisited later in this article. Durrant et al. (2018) also identified that the relative influence of local agency versus geographical or domain-specific limitations to acceleration remained an unexplored topic in their research and recognized that future work could explore this further. Ehnert

Table 2. Overview of the five acceleration mechanisms outlined by the ARTS project for urban sustainability transitions.

	Definition (Frantzeskaki et al. 2017)	Impact (Gorissen et al. 2018)	Relationship with Other Mechanisms (Durrant et al. 2018)	Tensions (Ehnert et al. 2018)
Upscaling	The growth of members, supporters, or users of a single transition initiative to spread new ways of thinking, organizing, and practicing	Due to lack of quantitative data, assessing the impact was not possible	Supports embedding Supports acceleration	Tension between the management of quantity and the management of quality (the limits of growth)
Replicating	The take up of new ways of doing, organizing, and thinking from one transition initiative by another	Helps to get things going locally while increasing the diversity of system change in the city region	Supports upscaling	No tensions identified
Partnering	The pooling and/or complementing of resources and capacities to ensure the continuity of new ways of doing, organizing, and thinking	Results in knowledge sharing via education, resource sharing, and the joint organization of events showcasing sustainability solutions to the wider public	Supports upscaling Supports embedding	With limited resources, tensions can occur between building partnerships and the "core activities" of an initiative
Instrumentalising	Tapping into and capitalizing on opportunities provided by the multi-level governance context of the region to forge resources for the continuity of the operation of the initiative	The ability to mobilize both people and money to advance sustainability locally	Supports replication Supports upscaling Supports embedding	Tension between the dependence on external sources and the autonomy of the initiative
Embedding	The alignment of old and new ways of doing, organizing, and thinking to integrate them into city-regional governance patterns	Allows the anchoring of more sustainable practices in local governance structures via institutionalization and routinization	Supports upscaling Supports acceleration	Struggles over political leadership and ownership between incumbents and the initiatives

Source: ARTS (2021).

et al. (2018) began to address this recommendation by exploring the commonalities and differences between the dynamics in which acceleration mechanisms unfold across numerous city-regions. Accordingly, they executed a comparative analysis of five diverse European city-regions (Brighton (UK), Budapest (Romania), Dresden (Germany), Genk (Belgium), and Stockholm (Sweden)). Interestingly, similar tensions characterized the acceleration mechanisms across all five city-regions. We briefly summarize these tensions in the fifth column of Table 2.

Research by Frantzeskaki et al. (2017), Gorissen et al. (2018), Durrant et al. (2018), and Ehnert et al. (2018) begins to address the recommendation of Kern and Rogge (2016) by identifying the varying roles that actors need to play to ensure a more rapid unfolding of transitions. However, we believe there is opportunity to further contribute to this understanding by analyzing TIs with a "shared purpose." Accordingly, we understand that shared purpose to be the development of a hydrogen network to assist in the large-scale decarbonization of England's North West region. In recognition of the fact that "green" innovations like hydrogen technologies can face additional struggles that can hinder their development (Geels 2019), we also contend there is a need to further explore the challenges associated with acceleration of sustainability transitions and how policy makers and other influential actors might address them (Markard, Geels, and Raven 2020). In doing so, we assert that there is merit in integrating concepts presented earlier in this section with the acceleration-mechanisms framework. Therefore, throughout the remainder of this article, we seek to begin to address the following research questions:

- What examples of acceleration are exhibited by hydrogen-transition initiatives in the North West region?
- How can exploration of numerous transition initiatives with a single shared purpose enhance research on acceleration mechanisms?
- What strategies could be adopted to ensure continuity of the acceleration of the North West region's transition to hydrogen?

Methodology

Throughout this research, we adopted a case-study methodology to understand a single case and its activity within important circumstances (Stake 1995, xi). Stake (1995, 2) explains that a "case" can be understood as a complex "integrated system" that has "a boundary and working parts." For clarification, the "case" that we explore in our study is the hydrogen agenda being pursued within the bounds of the North West region of England. Case studies are very descriptive in nature and can take various forms including reliance on interview transcripts and written and visual documents (McQueen and Knussen 2002). In our research, we employed semi-structured interviews as they allowed for a blend of closed and open-ended questions with opportunity for follow-up (Adams 2015). Participants included representatives from industry, local and national government, and public bodies. In total, we interviewed 21 participants between October 2019 and September 2020.[2] The duration of the interviews ranged between 43 and 76 minutes (see Appendix A for further details). To develop our interview guides, we drew upon concepts from the analytical framework developed by Kern et al. (2016) which outlines influential factors in the realization of demonstration projects. Accordingly, we questioned participants on one or more of the following four socio-technical considerations depending on their respective roles in the prospective hydrogen transition: technical characteristics, policy and regulation, network engagement, and social license to operate. In relation to these socio-technical factors, we asked participants to describe their particular initiatives and to identify factors responsible for driving their success. Furthermore, respondents were asked to describe any challenges that they faced and to provide suggestions on improvements that could be made. We transcribed the audio recordings from these interviews using the guide proposed by Azevedo et al. (2017). In addition, we adopted thematic analysis because of its power in helping to understand a set of thoughts and experiences across an entire data set (Kiger and Varpio 2020) and adhered to the six phases provided by Braun and Clarke (2006). To assist in generating initial codes, we used NVivo due to its ability to store and manage large volumes of data. The resultant codes were collated to identify, name, and refine themes. As will be discussed accordingly, these themes highlighted evidence of acceleration mechanisms being adopted by TIs in the region and provided valuable insight for deeper exploration of the challenges faced in instrumentalizing.

Hydrogen-transition initiatives and actors in the North West

TIs are characterized by the collective action of multiple actors in the city-region that aim to drive transformative change toward environmental sustainability (Durrant et al. 2018). Drawing upon secondary data such as articles, reports, and press materials, we identified numerous hydrogen TIs in the North West

region. These sources are outlined in Table 3 and discussed further throughout this subsection. TIs varied in form and included initiatives of a technical, policy, and hybrid nature. In this article, we refer to hybrid initiatives as those which have members from political, academic, industrial, and/or commercial backgrounds. This review also assisted efforts to identify and select participants for the interviews that we conducted.

The North West of England is home to the HyNet project that seeks to decarbonize the region by producing, storing, and distributing hydrogen together with carbon capture and storage technology (CCS) (Progressive Energy 2020b). In 2017, Cadent Gas, the UK's largest gas distribution-network operator, published a technical report that envisioned development of a hydrogen-conversion project in the Liverpool-Manchester cluster (Cadent Gas 2017). The proposal was designed by Cadent Gas to represent a "no regrets" pathway toward a meaningful reduction in emissions while still providing the opportunity for further expansion. As an extension to this work, the following year, Cadent Gas published the "HyNet North West" report (Cadent Gas 2018). The document outlined a proposal for an integrated low carbon hydrogen production, distribution, and CCS project across Liverpool, Manchester, and Cheshire. Since this publication, the HyNet project has birthed an array of workstreams such as those dedicated to hydrogen production as well as CCS. In October 2021, the UK Government announced that the HyNet project had been selected to progress within "Track 1" of the UK government's cluster-sequencing process that was designed to identify which industrial clusters are suited for deployment in the mid-2020s (Hands 2021). This means that the project will begin decarbonizing industry from 2025 (HyNet 2021a).[3]

Table 3. Overview of Hydrogen Transition Initiatives in the North West Region.

	Name	Description	Actors Involved	Project Status
Technical Transition Initiative	HyNet	Aims to be the UK's first net-zero cluster through the implementation of a hydrogen energy and CCUS project (HyNet 2021b)	Numerous Industrial Partners Academia Policy Makers	CCS stream: Front End Engineering Design (FEED) underway Hydrogen: FEED underway
	Project Vanguard	Project delivery, operations, and maintenance of the first green hydrogen-fueling station in the North West (Storengy 2021; Fuel Cells Works 2020)	Industry Policy Makers	Operational
	Project Centurion	Envisions to demonstrate a 100 MW "Power 2 Gas" energy-storage system which can produce low-carbon hydrogen for heat, decarbonization of industry, and transport fuel (UKRI 2021b; Storengy 2021)	Numerous Industrial Partners	Feasibility study complete
	HySecure	The demonstration of the deployment of grid-scale storage of hydrogen in a salt cavern (Stevenson 2019; Storengy 2021)	Industry	Feasibility study complete
	HyDeploy	The demonstration of up to 20% volume hydrogen-gas blends in UK homes. In the second and third phase, there will be a large demonstration in the North West (HyDeploy 2021a)	Industry Academia Public Body	First trial at Keele University complete Hydrogen blending started at Winlaton as part of Phase 2
	Liverpool Hydrogen Bus Trial Project	The purchase of 25 publicly owned hydrogen fuel-cell buses to improve air quality and work toward a zero-carbon economy (LCRCA 2019, 2020)	Numerous Industrial Partners Manufacturers Policy Makers	Buses due to enter service in 2022
Policy Transition Initiative	Energy and Clean Growth Strategy (C&W Local Enterprise Partnership(LEP))	By 2040, Cheshire and Warrington's energy system will be based on low carbon power and heating systems. The area could lead in several areas including hydrogen (Cheshire and Warrington LEP 2018)	Local Enterprise Partnerships	N/A
	Climate Emergency Taskforce (Cheshire West and Cheshire Council)	A cross-party taskforce to understand and plan for the implications, risks and new opportunities for the borough presented by climate change. This will shape how the borough responds to threats and opportunities presented by the Climate Emergency (Cheshire West and Chester n.d.-a)	Policy Makers Industry	N/A
Hybrid Transition Initiative	North West Hydrogen Hub/Alliance	To bring together regional and national stakeholders and increase the public awareness of hydrogen as well as to present a compelling case for the North West to receive vital government support (NWHA 2020)	Numerous Industrial Partners Academia Policy Makers	N/A

As outlined in Table 3, there is also a portfolio of additional technical hydrogen initiatives across the region. While HyNet proposes to deliver a full hydrogen network, the other technical projects outlined tend to focus on individual components of the hydrogen system. For example, Project Centurion and Project Vanguard offer alternative sources of hydrogen production using different technologies to HyNet. In terms of hydrogen storage, Project Centurion and HySecure are examining the feasibility of large-scale hydrogen storage in salt caverns. For end-use applications of hydrogen, the region is home to numerous switching, transport, and domestic demonstration projects. In the transport sector particularly, hydrogen buses are expected to be deployed in the Liverpool City Region from 2022 onwards.

In addition to the technical projects, there are other initiatives which are actively driving the hydrogen agenda in the region forward. For example, the NWHA seeks to provide a prominent voice in the hydrogen debate through its expertise and stakeholders (NWHA 2020). A full list of the alliance's partners is available in NWHA (2021). In a similar vein, local policy makers are increasingly recognizing the importance of hydrogen in terms of the decarbonization opportunities it presents for the region (see Table 3 for further information).

The acceleration mechanisms framework: unpacking key findings

Throughout this section, we highlight evidence of acceleration mechanisms exhibited by the TIs listed in Table 3. First, we would like to provide clarification around the use of the term "mechanism." This could be interpreted as being positivistic in the sense that laws are formulated on the operative dynamics of the social universe (Turner 2001). In turn, this could be contradictory to the case-study methodology that we adopted. Therefore, it is important to note that we do not use this term to imply that mechanisms are "recipes for success" (Frantzeskaki et al. 2017). Instead, we use "mechanism" to distinguish between the five different forms of acceleration and recognize that these may not be applicable to all the transition initiatives explored.

Replicating

Similar to findings presented by Gorissen et al. (2018), our results indicate three different dimensions of replication: inward, internal, and outward. Our findings also support those of Durrant et al. (2018) who identify strategy replication as a core activity intrinsic to this mechanism. However, we also observe "technology replication" which research has not explicitly mentioned. In examples of technology replication, we see the sustainable technology adopted by one initiative replicated within another.

Throughout the region, replication occurs at both the inward and internal level. For example, policy-based TIs have replicated national government-decarbonization strategies within their own city-region policy instruments. To provide an example, in 2019, Cheshire West and Chester Council declared a climate emergency that pledged their commitment to reaching net-zero emissions by 2045. As part of the council's related "Climate Emergency Response Plan," the necessity of supporting blue and green hydrogen development was identified (Cheshire West and Chester Council 2021). The plan recognizes a need to take advantage of the UK government's "Ten Point Plan for a Green Industrial Revolution" when highlighting that the area has a unique opportunity regarding hydrogen. Likewise, Cheshire and Warrington Local Enterprise Partnership (LEP) published the local "Energy and Clean Growth Strategy" which heavily referenced national policy documents such as the "Clean Growth Strategy" and the "Industrial Strategy" (CWLEP 2018; Her Majesty's Government 2017a, 2017b). These examples of inward replication have also facilitated internal strategy replication across various technical initiatives in the region. For example, the climate emergency declared by Cheshire West and Chester is used to provide context and motivation for the HyNet initiative in their "Vision" document (Progressive Energy 2020b). Similarly, the Liverpool City Hydrogen Bus initiative also recognizes Liverpool City Region's ambition to reach net-zero by 2040 and details how hydrogen buses will contribute toward achieving this target.

Hydrogen initiatives across the region also exhibit internal and outward technology replication. Concerning the former, hydrogen salt caverns developed by the HySecure initiative are anticipated to be utilized as a means of large-scale hydrogen storage within future extensions of the HyNet project. While the salt-cavern storage technology is not yet operational, this shows the taking up of new ways of thinking from one initiative by another. The HyDeploy initiative has shown outward technology replication of the gas grid-entry unit used to supply blended hydrogen to homes. The unit was first pioneered at the Keele trial site, during Phase 1, and has since been replicated at the Winlaton site during Phase 2 (Madgett 2021).

Upscaling

Our findings highlight numerous examples of upscaling exhibited across hydrogen initiatives in

the region. Accordingly, we observe several activities such as project and partnership developments, raising awareness, and the growth of transition initiatives (Durrant et al. 2018). To elaborate, as part of the industrial fuel-switching workstream, the HyNet initiative has partnered with several major industrial leaders in the region, including Essar, NSG, and Unilever (Progressive Energy 2020a). Collectively, the partnerships formed between industry and the HyNet project will facilitate decarbonization through the utilization of low-carbon hydrogen as a fuel. Likewise, the HyNet project has also partnered with InterGen to generate zero-carbon power using hydrogen gas-turbine technology (Progressive Energy 2021a). The Liverpool City Hydrogen Bus Project provides another example of partnership development as it has recently secured a supplier for the hydrogen-bus fleet (Mersey Travel 2021). The NWHA initiative has also shown growth in partnerships and memberships over recent years. In 2020, the group welcomed five members and has since recruited a further five (Heynes 2021).

Several initiatives have raised awareness through an array of media channels. In 2020, both the HyNet and HyDeploy projects featured in national British Broadcasting Corporation (BBC) news articles (BBC 2020; Harrabin 2020). The HyNet project also featured in other reputable newspapers and magazines in the energy sector such as: *Gas World* (Wright 2021), *Edie* (Edie Newsroom 2021), and *Offshore Energy* (Bojan 2021). Despite this coverage, one interview participant expressed concerns that objectives of the TIs within the region might not necessarily be understood by the general public (Interview 14). This view was supported by another participant who claimed that there was "room [for the North West industrial cluster] to shout louder" (Interview 6).

We observed project development as a means of upscaling in two different forms. In one sense, project development has allowed technical initiatives to progress through various stages of the engineering lifecycle. To provide an example, since publishing an initial feasibility report in 2018, the HyNet project has diverged into multiple workstreams such as "HyNet Hydrogen" and "HyNet CCS." Both of these workstreams have completed pre-FEED studies and progressed to the FEED phase with a final investment decision expected in 2023 (Progressive Energy 2020b). Similarly, the Vanguard initiative is now operational. In another sense, project development has led to the growth of users of a single initiative. To elaborate, Phase 2 of the HyDeploy trial supplies hydrogen to residents across approximately 670 homes (Madgett 2021). This is a much larger number of buildings than Phase 1 of the project that supplied hydrogen to 101 domestic homes and 30 university buildings at Keele University (HyDeploy 2021b). Phase 3 is also expected to supply a large number of homes in the North West region (HyDeploy 2021a).

The challenges associated with upscaling were discussed by participants throughout the interviews. When asked how technical initiatives could be scaled up, respondents highlighted numerous challenges associated with securing funding. For example, one participant made the following statement: "Well, I think it's probably linking back to funding … I think it's the crucial one. It's early feasibility and you still need to do full FEED, you know, all the stages of the engineering process. So, it would need funded." (Interview 5).

This aligns with Durrant et al. (2018) and Ehnert et al. (2018) who observed tensions concerning the limited availability of financial resources for upscaling.

Instrumentalizing

Like Durrant et al. (2018), we also identified the exploitation of funding schemes to be one of the most common forms of instrumentalizing. Numerous interview respondents highlighted that they had received funding from a range of providers such as Innovate UK, UK Research and Innovation (UKRI), Office of Gas and Electricity Markets (OFGEM), LEPs, and local authorities. While participants recognized the value of funding in allowing their respective projects to progress, they also identified several challenges in relation to funding opportunities. We discuss these challenges in greater depth in the next section of this article.

Durrant et al. (2018) provide examples of TIs exploiting existing policies to forge resources for the continuation of initiatives. However, of all participants interviewed in our study, only one was able to identify a policy which could potentially be utilized to make the economics of their initiative more favorable – the "Renewable Transport Fuel Obligation" (Interview 8). In fact, most participants perceived existing policies to be non-supportive of hydrogen technologies. Often, policy limitations were discussed in relation to current carbon-taxing regimes (Interview 1, 6, and 15). Correspondingly, like Ehnert et al. (2018), we also identified TIs' dependency on grants and policy incentives as a tension.

Partnering

Similar to upscaling, we found that hydrogen initiatives in the North West region showed considerable evidence of partnering. Interview respondents discussed several "meet-up" groups which Durrant et al. (2018) and Gorissen et al. (2018) have

identified facilitate the widespread connections between actors of numerous initiatives. For example, interview participants referred to the NWHA, the Cheshire Energy Hub, and the North West Business Leadership Team frequently throughout discussions. The perceived advantages of such groups included evidence building, risk sharing, the development of relationships, and, in some cases, the development of contracts. Regarding the NWHA initiative, one participant recognized value in receiving updates on the status of other hydrogen initiatives in the region that could then be relayed to national stakeholders such as CEOs and governmental departments (Interview 17). Durrant et al. (2018) explain that lobbying to government has an important role in partnering as it can enable embedding by altering both local and national structures (Durrant et al. 2018).

We also observed challenges associated with partnering. As outlined by Ehnert et al. (2018), limited resources have the potential to bring about conflict and rivalry between initiatives and, in turn, to hamper efforts in developing partnerships. While this does not seem to have constrained partnering across the TIs we explored, it certainly appeared to prohibit partnering with initiatives that are similar in nature outside of the city-region. To elaborate, numerous participants expressed a desire to collaborate with hydrogen initiatives in other industrial clusters due to benefits such as cost reductions, building economies of scale, and knowledge sharing. However, despite these activities they felt they were unable to do so due to the competitive environment created by UK government-funding streams which were often perceived as a "barrier to collaboration" (Interview 14). This appears to align with the findings of Ehnert et al. (2018) who identify that deceleration and stagnation may also unfold in parallel to acceleration.

Another subtle challenge identified for partnering centered around the development of a "common voice" (narrative) to promote the case for hydrogen initiatives in the region to the national government. Participants discussed this challenge in relation to two different actors – local policy makers and industrial organizations – though the latter was discussed less frequently in comparison. Instead, participants mainly discussed the political complexity of the North West and the lack of so-called "political coherence" (Interview 3). To elaborate, interview respondents identified a need for more consistent messaging between local authorities and LEPs within the region (Interview 6 and 8). This challenge has not been observed in previous research, yet it is an especially important observation given the role that government has in facilitating embedding.

Embedding

We observed only a few instances of embedding across the TIs explored. We believe this signifies the importance of addressing some of the previously identified challenges associated with other mechanisms to facilitate further embedding. The most common forms of embedding in the region relate to policy initiatives which have successfully adopted sustainable policies and strategies within their respective organizations. For example, as well as declaring their own climate emergency, Cheshire West and Chester Council have pledged their commitment to low-carbon technologies in their "Sustainability Statement of Intent" (Cheshire West and Chester n.d.-b). Likewise, Cheshire and Warrington LEP have partnered with private and public sector organizations to develop their "COVID-19 Recovery Plan" that recognizes sustainability as one of the four key improvement areas. In this document, the LEP identifies the progression of opportunities for hydrogen and CCS as an initial focus as part of wider decarbonization of the North West industrial cluster (CWLEP 2021, 26). Cheshire and Warrington LEP also pledge their commitment to supporting the delivery of the HyNet project within the plan.

Technical initiatives in the region also show emerging examples of embedding "new ways of doing." The HyDeploy initiative successfully obtained an exemption from the "Gas Safety (Management) Regulations" meaning that larger volumes of hydrogen could be supplied to buildings on the trial sites at Keele and Winlaton. Furthermore, 100% hydrogen-fired glass production is currently being demonstrated at the Pilkington UK's St. Helens facility (as part of the HyNet industrial fuel-switching initiative) (Progressive Energy 2021b). Such demonstrations are important as they allow the anchoring of more sustainable practices within city-regional governance patterns (Gorissen et al. 2018). Though, we would like to clarify that not all initiatives have progressed to the same level as others.

Contributions to the debate on the acceleration of transitions

Emphasizing the significance of instrumentalization

Durrant et al. (2018) explain that the acceleration of TIs is heavily dependent on the scaling up of sustainable practices and changes to existing structures, and thus making upscaling and embedding mechanisms significant to continued acceleration. While we agree that these mechanisms are essential, our findings unveil an additional consideration. To explain this further, we observe numerous examples

of upscaling exhibited by the TIs explored. Our earlier discussion unveiled examples of project development, partnership building, and raising awareness across several TIs. Yet despite the supportive role that upscaling has shown to have on embedding, as identified by Durrant et al. (2018), we observed limited examples of this mechanism by comparison. We contend that this could be due to wider challenges associated with instrumentalizing. For example, we identified that, in some cases, upscaling was constrained by the limited availability of financial resources such as funding streams. This emphasizes the affect that challenges faced in instrumentalizing have on a TI's ability to upscale as a mean to embed sustainable practices within city-regional governance patterns. Therefore, we argue that instrumentalizing should also be recognized as being significantly important in the acceleration of TIs.

Understanding the challenges of instrumentalization

Earlier in this article, we highlighted that instrumentalizing was often curbed by factors such as the ability to secure financial support and to exploit existing policies. Throughout this section, we aim to provide a greater understanding of why such challenges are faced by the TIs explored. Participants discussed several perceived issues related to funding streams as well as their implications. These issues are summarized in Table 4. In relation to the first challenge, one participant expressed concerns that once funding pots/resources are depleted, there is not always a guarantee of further project development. These findings align with Durrant et al. (2018, 1547–1548) who also identified the tendency for some projects to "abruptly end" once funding had finished. Interestingly, this challenge does not seem to prevent instrumentalizing in the first instance but rather points to issues for sustained instrumentalizing. In this sense, it is not surprising that some hydrogen initiatives in the region (HyDeploy, Project Vanguard and HyNet), that have secured numerous allocations of funding, have progressed to the FEED, demonstration, or operational phase.

The two remaining challenges in Table 4, unveil factors which have not been identified in previous literature relating to the ARTS project. This could be a result of the scale and ambition of the TIs we explored. For example, initiatives like the HyNet and HySecure projects will require significant investment and financial support due to the large-scale infrastructure requirements of the technologies envisioned. This aligns with the second challenge identified in Table 4. Concerning the level of investment required for certain hydrogen initiatives versus the amount of funding awarded, one interview participant made the following statement:

> But, my take, at the moment, is that the main barrier is funding availability. So, clearly I welcome the announcement in the budget of around £800 million for the deployment of two hydrogen clusters and that's hugely exciting and I'm sure that HyNet will be very well placed to hopefully secure that funding. But even that doesn't necessarily go far enough … is my view and understanding. (Interview 17)

If TIs are unable to secure the required levels of funding, project development could be stalled. In turn, this could have serious implications for private investment. To elaborate, one interview participant explained that investors would be more likely to invest in technologies which had reached the demonstration phase. Participants contended that it was the role of government to financially support initial development of first-of-a-kind technologies like those proposed in the HyNet and HySecure projects (Interview 6). It is, however, worth noting that since the interviews were conducted, numerous additional funding streams applicable to hydrogen initiatives in the region have been announced. These streams include the £240 million "Net-Zero Hydrogen Fund" and £1 billion "CCUS Infrastructure Fund."

The final challenge was discussed less by participants in comparison but still remains an important consideration. One respondent referred to UK State Aid funding stipulations and how, in some cases, match funding from industry was required (Interview 14). To provide an example of this issue, the IDC will provide up to £170 million in funding which is expected to be matched by £262 million from industry (UKRI 2021a). The same participant also discussed the implications of this development in terms of shareholders not being able to continuously fund hydrogen initiatives despite their demonstration of significant potential. For the technical initiatives we have explored, this signifies the importance of projects being economically viable, as well as sustainable, to ensure their continuation. As, after all, many of the actors driving such initiatives are commercial entities.

Table 4. Challenges identified by participants in relation to the funding of hydrogen initiatives.

Instrumentalizing Challenges	Implications
Not always certainty of the next stage of funding	Projects which do secure funding have the potential to remain trapped at the feasibility level
Some technologies require a significant amount of investment	Initiatives with large-scale infrastructure requirements may be delayed in project development or may never reach fruition
State-aid rules which (sometimes) require match funding from industry	Shareholders cannot sustainably keep funding projects with no revenue generated

As we highlighted previously that only one interview respondent was able to identify an existing policy mechanism which could help build the economic case for their respective hydrogen-transition initiative. To highlight the significance of this challenge, various policy mechanisms have been developed by UK Government and other public bodies to support the generation of low-carbon electricity. These include "Feed-in-Tariffs" (FiTs), "Contracts for Difference," and the "Renewable Heat Incentive." However, the same level of institutional support has not mirrored for hydrogen technologies.

Recommendations for policy makers

So far, our findings have contributed to the question posed by Grubler, Wilson, and Nemet (2016) concerning "what it takes" for transitions to be accelerated. For example, empirical examples of each mechanism provided insight into the activities TI actors have adopted to actively pursue the progression of their respective projects. Accordingly, these findings begin to contribute toward the recommendation by Kern and Rogge (2016) for future research to explore the roles which numerous actors have in ensuring that transitions with significant urgency unfold rapidly. This subsection extends on this point further by suggesting several recommendations for policy makers to address the challenges earlier identified for instrumentalizing.

We previously discussed research conducted by Roberts and Geels (2019) that investigated intervention strategies which could encourage the breakthrough of socio-technical systems. To contribute to our final research question, we borrow concepts from this study to inform recommendations for policy makers and the policy instruments they could adopt to address the previously highlighted challenges for instrumentalizing. To integrate these proposals with the acceleration-mechanisms framework, we also highlight how they could facilitate further acceleration of the TIs explored (see Table 5). These recommendations are applicable mainly to policy makers but will require engagement with other actors such as academics, regulators, and private sector organizations.

Conclusion

Hydrogen can assist in addressing the global crisis of climate change by significantly decarbonizing a range of heavy-emitting sectors. The North West of England boasts a portfolio of hydrogen initiatives which are intrinsic to the establishment of a hydrogen network in the region. However, given the need to decarbonize within a rapid timeframe (IPCC 2018), we explored how the region's transition to hydrogen could be accelerated. In doing so, we positioned this research in the field of sustainability transitions studies and discussed an emerging body of literature which has begun to explore how such transitions could be accelerated. Accordingly, we identified an opportunity to apply the ARTS project's acceleration-mechanisms framework in a novel way. To elaborate, we analyzed numerous TIs in the North West region which shared the same purpose of seeking to establish a hydrogen network to assist in large-scale decarbonization.

When showcasing our findings, we provided empirical evidence of each mechanism exhibited by TIs in the region. We also generated novel findings concerning the challenges faced in the acceleration of TIs. For example, when discussing partnering, we identified that actors faced difficulties in establishing a "common voice" to promote the case for hydrogen in the region. While research by Ehnert et al. (2018)

Table 5. Recommendations for actors concerning the challenges to instrumentalizing.

Recommendation	Justification	Possible Policy Instrument(s)	Possible Policy Approach(es)	Actors Responsible
To deliver funding streams which allow successful candidates to progress to the demonstration phase	To allow sustained instrumentalizing for transition initiatives and thus facilitate the embedding of 'new ways of doing'	State-led investment programs Demonstration projects	Classic steering Interactive network governance	Policy makers, industry, academia, and regulators
To carefully consider the amount of funding awarded to projects in relation to the level of investment required	To encourage project development within transition initiatives (upscaling) and thus facilitate the embedding of 'new ways of doing'	Roundtable discussions and debates State-led investment programs	Interactive network governance Classic steering	Policy makers, industry, businesses, and other funding providers
To collaborate with numerous actors with far greater urgency to develop and deliver policy mechanisms which make the economics of hydrogen more favorable	To provide further instrumentalizing opportunities for transition initiatives and thus facilitate subsequent upscaling and embedding	Roundtable discussions and debates Regulation and laws Green subsidies and incentives	Interactive network governance Classic steering Market model	Policymakers, industry, academia, businesses

had observed similar tensions for partnering across different sectors and domains, we also found this to occur throughout the same sectors and domains – especially within the public sector.

Our discussion identified that challenges attributable to instrumentalizing had a constraining effect on a TIs ability to upscale and embed. Thus, making instrumentalizing significant to the successful continuation and acceleration of TIs. Accordingly, we unpacked several reasons why initiatives in the region had faced difficulties in instrumentalizing. The fundamental issues we included the considerable sums for investment required for large-scale technologies, the uncertainty surrounding future funding opportunities, and the lack of supportive policies to build the economic case for hydrogen technologies. To propose how actors might address these challenges, we drew upon concepts from Roberts and Geels (2019) to inform our recommendations to policy makers. We then integrated our recommendations with the acceleration-mechanisms framework to suggest how they could facilitate further acceleration for the TIs explored.

Recognizing that the North West is just one of the UK's heavy-emitting industrial clusters, we believe that future research could benefit from exploring the transferability of these findings to other clusters where technological and political priorities may differ. In doing so, this would contribute further to the academic literature concerning the acceleration of sustainability transitions while simultaneously assisting in informing UK decarbonization policy. Furthermore, we recognize that throughout this article we have focused specifically on how the transition to hydrogen could be accelerated. However, we have not explored what the implications of deliberately accelerating sustainability transitions might be. Therefore, future research may also wish to explore whether there are any unintended consequences to sustainability transitions occurring "too quickly."

Notes

1. Existing literature concerning the acceleration of transitions is outlined in greater detail in the next section.
2. This research obtained ethical approval from the University of Chester's Faculty of Science and Engineering Research Ethics Committee on July 10, 2019 under reference number 132/RE/CE. All participants were sent consent forms prior to their participation in this study. Interviews were conducted only once consent was received.
3. This condition is anticipated to apply if the project represents value for money for the consumer and the taxpayer (Hands 2021).

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Appendix A.

Overview of semi-structured interviews conducted between October 2019 and August 2020.

Interview Code	Date	Stakeholder Type	Role in Hydrogen System
IN1	October 4, 2019	Industry	Storage
IN2	October 7, 2019	Industry	CCUS Infrastructure
IN3	October 8, 2019	Project Development	Whole System
IN4	October 10, 2019	Technology Design	Production
IN5	October 11, 2019	Design Engineer Project Management Consultancy	CCUS Infrastructure
IN6	October 28, 2019	Regeneration Business	Production
IN7	November 7, 2019	Chemical Company	Production
IN8	November 13, 2019	Industrial Gases and Engineering	Production and Transport
IN9	November 18, 2019	Rail Industry	End Use – Transport
IN10	November 27, 2019	Energy Company	Production Source
IN11	December 2, 2019	Gas Distribution Network	Distribution
IN12[a]	December 6, 2019	Chemical Company	CCUS Infrastructure
IN13	January 10, 2020	Engineering Company	Fuel Cells
IN14	February 13, 2020	Construction and Engineering Company	CCUS Infrastructure Transportation End Use – Fuel Switching End Use – Transport
IN15	February 14, 2020	Advisory Group	Production and CCUS Infrastructure
IN16	February 17, 2020	Public Body	Research and Innovation
IN17	February 25, 2020	Local Enterprise Partnership	Business Growth
IN18	March 3, 2020	Local Council	Local Policy
IN19	September 9, 2020	Gas Transmission Network System Operator	Transmission
IN20	September 17, 2020	Government Department	Whole System

[a]Two interviewees were present for this interview, thus bringing the total number of participants to 21.