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Industry Stakeholder Perceptions of Carbon Capture, Utilization, and Storage: The Case Study of the Tees Valley Industrial Cluster

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Abstract: Carbon capture, utilization, and storage (CCUS) is an essential mitigation technology to contribute to the Net Zero transition. It captures carbon dioxide (CO_2) emissions from industry processes and either purifies and inserts the gas again in the circular economy (utilization) or transports it to a suitable underground storage, stopping emissions. The United Kingdom (UK) has unique geology, skills, and infrastructure and consequently a strategic advantage for CCUS when compared to other countries, especially the coastal North Sea regions (e.g., Tees Valley). This study focused on the Tees Valley Industrial Cluster to understand the constraining and enabling factors of the CCUS technology deployment, from the perspective of local experts and practitioners, whose role is to implement actions to reduce GHG emissions. Two workshops were held to explore practitioners' attitudes towards the technology, perceived benefits of the technology, barriers and enablers for implementation and factors that would need to be in place to support technology implementation. Qualitative data collected in the workshops were analyzed to identify common themes. Participants agreed that business and industry sectors must play their part in mitigating climate change. They also agreed that it is fundamental to support the green transition and the implementation of net zero-related technologies. The perceived benefits of CCUS are the contribution to fulfill Environmental, Social, Governance (ESG) standards and an increased ability to attract young workers, interested in sustainability. Barriers for implementation include lack of knowledge about the technology, costs of the technology, volatility of the carbon markets, political uncertainty, risks, and negative public perceptions. Regional factors such as local political support were identified as crucial to the success of technology deployment. A reliable UK Industry Strategy, investment in the technology and supply chain, local investment in skills, knowledge, education, and research were considered essential to ensure further technology adoption.

Keywords: industry, enablers, barriers, UK net zero, transition

1. Introduction

In the United Kingdom (UK), greenhouse gas emissions (GHG) from the business and industry sectors and from the waste management sector account for around 18.7% and 5% of the total GHG emissions, respectively [1]. Under the Climate Change 2008 Act (amended in 2019), the UK government legislated to reduce its GHG emissions by 100% from the 1990 baseline by 2050, i.e., the balance between the carbon dioxide (CO_2) released into the atmosphere, and the CO_2 removed from the atmosphere must be net zero. There are seven industrial areas which are still reliant on fossil fuels and contribute significantly to the total GHG emissions of the industry and business sectors in the UK. Among these is the Tees Valley Industrial Cluster, in the Northeast of England. The Cluster is composed mainly by chemical, fertilizer, and utility industries. Reaching the Net Zero target in each UK industry cluster requires a collective action from the different industries that may include reducing GHG emissions through operational management, using renewable sources of energy, increasing efficiency of operations, changing behaviors, and implementing new technologies such as carbon capture and storage (CCS). This technology has been identified by the Committee on Climate Change (CCC) as an abatement option for the heavy industry such as cement, lime, ammonia, iron making, iron, steel, refining, and petrochemicals [2]. Carbon captured can be used in power and heat generation, bioenergy, waste-to-energy, and hydrogen production and could deliver "negative emissions" by directly capturing CO_2 from the atmosphere [3]. Carbon capture and storage (CCS) works by capturing CO_2 emissions before this reaches the atmosphere and by storing it safely underground in the wells emptied after oil and gas extraction. As there are currently numerous large-scale industrial CCS plants around the world (e.g., US, Canada, Asia, Europe) and, likewise, large amounts of stored CO_2, it has been suggested that captured CO_2 emissions should be used in other industrial processes rather

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than just stored [4], contributing to the circular economy. One option is the Carbon Capture and Utilization (CCU) technology, which convert CO_2 via physical or chemical processes into carbon-based products that can be sold in the market (e.g., polymers, methanol, and food products). The CCC [2] considers that Carbon Capture Utilization and Storage (CCUS) is crucial to the delivery of net zero GHG emissions, and strategically important to the UK economy. The former UK government vision set out plans for new competitive market in CCUS by 2035 to unlock investment and drive economic growth, adding £5 billion to the economy by 2050 [5]. The former UK government has also committed funds for low-carbon innovation between 2015 and 2021 through the Clean Growth Strategy and the Industrial Strategy Challenge Fund [6]. The UK is especially interesting for the implementation of CCUS technology due to its prominent and advanced technical Carbon Dioxide Utilization (CDU) research and development program [7]. Furthermore, the Tees Valley Industrial Cluster will be the home to one of the first fully integrated natural gas combined cycle power plant with an amine-based CCS unit that will deliver up to 860 MW of low-carbon electricity and store 2 million tonnes of CO_2 per year in offshore saline aquifers located in the North Sea.

Despite the advancements of the CCUS technology in terms of its technical and economic viability, its implementation is still very limited. There is, however, increasing research investigating factors influencing the adoption of CCUS with most research focusing on CCS. From this literature, some extrapolations can perhaps be made regarding CCU alone. For example, one reason given for the low implementation of CCS is the low priority given by state and non-state climate policy actors [8]. Seigo et al. [9] state that the large-scale deployment of CCS depends on the technological advances, the energy policies and government support, and public acceptance. Public perceptions about CCS implementation and technology acceptance have received increasing attention from research [7, 9–15], as well as public awareness of the technology [11, 16, 17]. However, research on the factors enabling and constraining CCU implementation has been more limited. Jones et al. [7] investigated lay perceptions of CDU technologies in the UK and Germany and showed little awareness of CDU in both countries. van Heek et al. [4] investigated perception and acceptance differences between laypersons and experts in of CO_2 utilization in the plastic production industry and found a positive perception of CO_2 utilization. In China, Li et al. [18] found a low public acceptance towards CCUS technology when compared to other low-carbon technologies. Arning et al. [19] investigated public perceptions and acceptance of CCU and CCS and found that public perception towards CCU was significantly more positive than towards CCS. Raimi et al. [20] focused on public perceptions of CCU benefits, risks, and acceptability in the US and found that people were positive about CCU in general unless CCU was in their home communities. These authors also found that women were more concerned about the technology and that people with a White background had more positive attitudes than Hispanic or Black respondents. Therefore, previous research [9, 14, 20] mostly focused on the technological elements of CCUS or public attitudes towards the technology. Lesser studies, however, have looked at the viewpoints of industry stakeholders, who actively participate in CCUS implementation. Research shows that public perceptions of climate change mitigation options usually differ from experts [20]. The Tees Valley Industrial Cluster, a distinct environment with its own regional dynamics, industrial legacy, and political support networks, is the subject of the study. While other research [17] examined CCUS in broader or worldwide contexts, this work offers a thorough case study of a particular and strategically significant UK industrial cluster. This study thus intends to contribute to fill the literature gap by analyzing the factors constraining or enabling the implementation of CCU, focusing on the views of experts and industry members operating in the Tees Valley Industrial Cluster, who are more knowledgeable of the technology and have direct interest in the success of the technology. It highlights the real-world obstacles and facilitators from the perspective of business and industry stakeholders.

2. Methods and Materials

The case study chosen to investigate industry perceptions of CCUS is the Tees Valley Industrial Cluster located in the Northeast of England. The Tees Valley region includes the towns of Hartlepool and Darlington and those covered by Teesside area, namely Middlesbrough, Stockton-on-Tees, Redcar, Thornaby, and Ingleby. Teesside is the urban and countryside area around the River Tees in the Northeast England. The economy was dominated by heavy manufacturing until deindustrialization in the late 1970s. Nowadays, the chemical production contributes significantly to Teesside's economy.

The Tees Valley Combined Authority strategy commits the region to achieve Net Zero by 2050 and states the intention of becoming a global leader in clean energy, low carbon, and hydrogen [21]. One top priority is to deliver large-scale CCU and over 4GW of hydrogen production by 2030. An anchor project for the decarbonization of industry cluster is the Net Zero Teesside (NTZ) project, whose objective is to implement CCU and develop a shared CO_2 infrastructure across the Tees Valley Industrial Cluster. The region faces the North Sea, whose storage capacity is estimated to be approximately 78 billion tonnes of CO_2 [5]. The Net Zero Teesside (NZT) aims to create the UK's first decarbonized industrial cluster by capturing the carbon emissions from power and industrial facilities at Teesside and storing the captured carbon in the North Sea. The NZT project is in line with the UK's broader net zero emissions target and is the pathway to decarbonize the industrial cluster at Teesside, able to capture and store up to 10 Mtpa of CO_2 by 2030 [22]. According to Net Zero Teesside, the cost of deploying CCUS is consistent with the net zero target set Committee on Climate Change. This cost is likely to change over time in line with the learning rates and the cost difference between new build and retrofits [22].

According to Witte [12], a deeper understanding of the views of local stakeholders can be better achieved through qualitative research methods. Therefore, in this study, two workshops hosted by researchers from Teesside University were undertaken to understand the views of experts and the stakeholders directly engaged with local businesses and industry (e.g., members of staff) in the Tees Valley Industrial Cluster. One workshop engaged members of staff of a food process plant located in the Tees Valley, and the other workshop engaged a diversity of stakeholders representing several organizations and the Tees Valley Industrial Cluster, namely industry workers, local policymakers, knowledge brokers, and researchers in the field of CCUS engineering. The first workshop was attended by 9 people in total (2 female and 2 male) with 7 people attending in-person at the company premises and 2 people attending online. The second workshop was attended by 23 people (7 female and 16 male), all attending in-person at the Net Zero Industry Innovation Centre (NZIIC) in Middlesbrough (Teesside). The workshops had a duration of about 2 h and included a 20 min presentation about

Table 1
Questions topics*

Question	Jones et al. [7]	Rationale
Stakeholders' knowledge about the technology	Conceptual considerations	*Should we do this?*
Stakeholder's preferred mitigation options for the business and industry sector	Conceptual considerations	*Should we do this?*
Stakeholders' views about the role of businesses and industry to contribute to the UK net zero target	Conceptual considerations	*Should we do this?*
Stakeholder's perceived risks about the CCU technology	Societal consequences	*What will happen if we do this*?
Stakeholder's perceived benefits of the CCU technology	Societal consequences	*What will happen if we do this*?
Stakeholders' perceptions of the barriers and enablers to the implementation of the technology	Techno-economic considerations	*Can we do this?*
Stakeholder's views on what should be in place to facilitate the implementation of the technology	Techno-economic considerations	*Can we do this?*

Note: *Following Jones et al. [7].

the techno-economic feasibility of CCU, a 20 min presentation on the UK net zero policy target and the carbon abatement options for the industry, and a 1 h 20 min discussion with participants. The formulation of questions posed in the workshop was guided by the framework developed by Jones et al. [7] (Table 1).

Notes from the workshops were written by DF (Lead author) and DH (co-author). These were combined, typed, and coded manually by DF in themes discussed in the workshop and sub-themes under themes. Final themes and sub-themes were refined and rearranged as shown in Table 2.

3. Results

In the workshops, on some occasions, stakeholders shared their views about the constraining and enabling factors of CCU and CCS interchangeably. Therefore, many stakeholder's views cover both

Table 2
Themes discussed in the workshops and refined themes and sub-themes

Themes arose in the workshops	Emergent themes and sub-themes from coding	Final themes and sub-themes for analysis
Acquisition of knowledge	Webinars through LinkedIn	Same
	In-person seminars	
	Online	
	Scientific information	
Preferred mitigation options	Reduce GHG emissions	Same
	Increase energy efficiency	
	Renewable energy	
	Steam as energy source	
	Hydrogen	
	Carbon Capture and Utilization	
	Energy produced from waste	
Role of industry to contribute to UK net zero target	Attitudes towards CCUS	*Theme:* Attitudes towards CCUS
Suitability of CCU for climate change mitigation in the UK	Attitudes towards CCUS	*Theme:* Attitudes towards CCUS
Barriers for implementation	Slow implementation	*Theme:* Barriers for CCUS implementation
	Lack of a solid strategy from the government	*Sub-themes:* Lack of knowledge
	Uncertainty	Costs of technology
	Lack of awareness about the technology	Volatile markets
	Cost	Perceived risks
	Lack of market for CO_2 captured	Political uncertainty and lack of strategy
	Lack of funding	Negative public perception
	Lack of skills and knowledge	
	Risk	
	Lack of infrastructure	
Enablers of implementation	Public and policy pressure	*Theme:* Enablers of CCUS implementation
	Favorable context	*Sub-theme:* Regional factors
	Good cross-party support	*Theme:* Factors that would need to be in place support CCU implementation
	Funding/Investment	

(*Continued*)

Table 2
(*Continued*)

Themes arose in the workshops	Emergent themes and sub-themes from coding	Final themes and sub-themes for analysis
	Skills and knowledge	*Sub-themes:*
	Education and research	Development of a reliable UK Industry Strategy
	Infrastructure	Increased funding/investment
	Positive attitudes to the industry	Investment in skills, knowledge, education, and research
	Good supportive local authority	Positive local attitudes towards the CCU industry
	Greater knowledge of benefits	
Benefits of CCU technology	Indirect jobs	*Theme: Benefits of CCUS*
	Positive image	*Sub-themes:*
	Knowledge/Expertise	Fulfill ESG targets
	Enabler of other mitigation options	Ability to attract young workers
	Security of CO_2 supply	Indirect jobs
		Positive image
		Enabler of other mitigation options
Risks for CCU	Obsolescence of technology	*Theme: Barriers for CCUS implementation*
	Lack of current knowledge about the technology	*Sub-theme:*
	Cost and uncertainty around the UK ETS	"Perceived risk" under theme "Perceived barriers for CCUS implementation".
	Industrial risks	
	Political uncertainty about net zero targets and funding	
	Lack of market for CO_2 captured	
	Negative public perception	
	Greenwashing	
	Investment risk	
	Waste/waste treatment	
	Infrastructure failure	
	Viability of the pipeline	
	Gas prices	

CCU and CCS. The discussion with stakeholders covered their attitudes towards the technology, perceived the benefits of the technology, perceived barriers and enablers for implementation, and perceived factors that would need to be in place to support technology implementation.

3.1. Attitudes towards CCUS

All workshop participants agreed that businesses and industry must play their part at mitigating climate change. They considered essential to support the green transition and the implementation of net zero-related technologies (e.g., CCUS, Hydrogen). Participants considered that most companies in the Tees Valley Industrial Cluster are already trying to contribute to the Net Zero target by implementing mitigation options at the operations level. One example where this is happening is the waste management industry, which was pointed out as having made significant environmental improvements in recent years, mainly due to public pressure and to pressure from the Environment Agency. This industry has been, thus, actively looking at options to reduce pollution and GHG emissions.

Participants thought CCUS can be part of the solution but not the only solution. They recognized that CCUS is a novel technology but considered that is not the only response to mitigation and that "*it should be part of the blend*" of technologies implemented. They believed that the technology could work as a quick fix for climate change mitigation. They stated, "*hopefully it is a short-term solution to help us building a greener system*" and that it "*could act as a transition technology*". They considered that preventing GHG emissions at the source was better than offsetting these emissions somewhere else. Participants supported more Carbon Capture Utilization (CCU) than Carbon Capture and Storage (CCS), which they considered unfeasible because "*there will be no wells to store carbon available for ever*". They thought that storing carbon on the ground would not solve the problem and that not all the carbon emissions can be captured. They believed that CCS is not a just mitigation option, as carbon dioxide does not disappear but remains stored underground for the next generations to "*sort it out, passing the problem to somebody else*". At the same time, participants considered there has been little progress in the deployment of the technology so and further development is required. They were confident that the CCU technology is efficient enough and that it could capture and utilize about 90% of the CO_2 emitted by the industry.

3.2. Perceived benefits of CCUS

Several benefits of CCUS were identified by participants, namely the fact that it provides indirect jobs, brings a positive image for the region, and it could be an enabler for other mitigation options. Participants also considered that CCUS could provide environmental and economic benefits that would help businesses and industry to fulfill their Environment, Social, and Governance standards (ESG) and consequently become more attractive to young workers. However, everyone recognized that

the implementation of CCUS has not been as fast as desired and that potential economic benefits have not been yet realized.

3.2.1. Contribution to fulfill ESG standards

Participants perceived environmental benefits as the most important benefits of CCUS when speaking with their personal "hat" on. However, with the "hat" of business and industry representatives, they considered that economic benefits were more important and that the technology would only be implemented if it was economically viable. One economic benefit identified was the additional revenue that could potentially be generated with the participation in the European Trading Scheme (ETS). They also considered that implementing the technology could prevent future regulatory restrictions and associated costs. Interestingly, participants admitted that even though the economic benefits were key for businesses and industry these should cover the "*environment box*". They consensually agreed that main benefits of CCUS should be environmental but that made economic sense. They recognized that GHG emissions mitigation and CCUS adoption was a good marketing strategy as it showed they were doing something about the environment. ESG standards were considered very important for small- and medium-scale enterprises (SMEs). Participants also mentioned they were aware of scientific findings showing a positive correlation between investment in green technology and business performance: "*CCUS could enhance the company performance*".

3.2.2. Increased ability to attract young workers

Participants have experienced potential employees asking about ESG credentials at interviews, concluding that "*ESG attracts workers*". They added that younger people recruited by the business and industry, who are recent graduates from university, have different expectations about how employers align with environmental principles, and are driving operational change with a sustainability focus. One participant mentioned that someone younger in his organization, who was connected to the owner, was driving the implementation of ESG-related targets.

3.2.3. Provision of indirect jobs

Participants considered that even though CCUS and hydrogen technologies would increase the offer for specialized jobs, the number of direct jobs generated by these technologies would still be low. Participants recognized that CCUS would mostly trigger indirect jobs in companies that would move to the region to take advantage of CCUS and hydrogen production (e.g., contractors). In general, they considered CCUS positive for the economy of the region. They suggested that the region-based businesses and industry could offer storage as a service and "*they could be the specialists at Teesside*" at producing CO_2, selling it, and/or redistributing it as well as at advising on the implementation of CCUS technology to other regions.

3.2.4. Positive image for the region

Participants mentioned that CCUS technology would contribute to create a positive image for the region in terms of action towards the Net Zero target. The Tees Valley region is already a world leader in cement production and CCUS could contribute to green the industry.

3.2.5. Enabler of other mitigation options

Participants thought that the adoption of CCUS and implementation of associated infrastructure could further enable the production of blue hydrogen, which could integrate reformed natural gas and captured CO_2. They believed the storage capacity of the Tees Valley could attract other industries to the region, acting as an enabler to produce blue hydrogen. They also considered the potential for increased circularity and simplification of the supply chain and believed these features would increase the viability of the new business models and the joint development required for the wider adoption of CCUS.

3.3. Perceived barriers for CCUS implementation

Stakeholders' views on barriers for current implementation and/or further expansion of the technology include political uncertainty, lack of knowledge about the technology, costs of the technology and volatile price for captured CO_2, perceived risks, and negative public perceptions.

3.3.1. Lack of knowledge about the technology

Participants have learnt about CCUS at in-person seminars, at online events, and at the social network LinkedIn. In-person events were held by several organizations in the region (e.g., Tees Valley Combined Authority, BP, Sabic, IMechE). They stated that BP (British Petroleum) is the main company driving the knowledge about the CCUS technology. They observed an overload of freely available information online, which has increased in recent years. They considered, however, that the information was very technical and not accessible to everyone. Participants felt that knowledge about CCUS has not been widely shared among businesses and industry, while renewable energy has been more promoted, which meant that people knew more about renewable energy technologies as a mitigation option than CCUS. Participants considered that because the methods, the chemistry, and the required capability are new, upskilling and workforce development are essential for the success of CCUS implementation.

3.3.2. Costs of the technology and volatile price for captured CO_2

Participants considered that CCUS is not financially attractive and that cost is a major challenge for implementation. The price volatility for captured CO_2 was perceived as a barrier for the implementation of this technology in the waste sector. Participants considered that environmental benefits would not be perceived before 5 years of implementation. They considered that a 20-year payback was a high risk for businesses to take without more supportive policies, even with the Net Zero policy goal and the Climate Change Act in place. There is a "*big energy and oil company corporation requirement for decarbonization projects to pay their way to shareholder interests*". They also noted the uncertainty around the UK Emissions Trading Scheme (UK ETS) and the demand for carbon credits, noting that carbon price is reducing, and consequently the incentive for businesses and industry to decarbonize is low. In addition, participants mentioned the lack of an established UK market for CO_2 captured with CCUS despite the existing demand of CO_2 from many industrial processes. Participants feared that a market for CO_2 produced via CCU technology would not be well established. On the other hand, they were hopeful that new markets for captured CO_2 could become an opportunity for the businesses and industry implementing CCUS to claim for negative GHG emissions.

3.3.3. Perceived risks

Participants pointed out infrastructure failures such as the danger of leakage or/and pipeline rupture, which could damage marine life, and asked "*what happens when CO_2 pipeline leaks*". Participants also pointed out the risks of the obsolescence of

technology, contemplating if CCUS was the right technology for the future. One participant stated, "*investment in a technology is difficult when it will be redundant at some point*". They suggested CCUS should be designed to allow retrofitting, as technology improves. Participants were also concerned about the viability of the CO_2 in the pipeline as the industry needs to maintain a standard flow rate of CO_2 and this may influence the minimum operating load of their facilities, which can be difficult for some. Another risk mentioned by participants was the disposal of unsafe materials produced during the CCUS process – "*the amine is very hazardous*", "*what happens when CO_2 pipeline leaks*". Some of these materials, however, could be re-utilized and incorporated by the circular economy. They recognized, however, that *"there will be always some disposal*" and questioned "*what to do with solvent and assets at their end of life*?".

3.3.4. Political uncertainty and lack of strategy

Participants pointed out that despite the existence of an Industrial Strategy in the UK, this has not been taken seriously. Participants pointed out that "*everyone is doing something independently, and emissions reductions are happening more like a way of making money*". They mentioned that in the UK there are several pots of funding and that everyone is trying "*to grab the money, without a strategy behind*". Participants were conscious that all political parties had a green agenda. However, they pointed out the uncertain support from the government in charge[1], which was not investing equally everywhere and had preferred "regions" to invest, called the "*government-friendly regions*". They also noted the opposition[2] party statements lowering the support to the Net Zero transition. Participants suggested that the level of uncertainty was hindering businesses, industry, and commercial investors to take the risk (transitional risk). They added that key stakeholders, such as BP, Equinor, or Kellas, may disengage from the CCUS technology and walk away from the UK due to the requirement for decarbonization projects to "*pay their way*" to shareholders' interests. The Tees Valley Combined Authority (TVCA), for example, already postponed their aspirational year to achieve Net Zero from 2030 to 2040. Participants believed that a new government could risk the region's Net Zero strategy since the TVCA mayor is not from the same party.

3.3.5. Negative public perception

Participants pointed out that among the reasons given by the promoters to postpone the hydrogen project in Redcar (Northeast England) was the negative perceptions of the local population about the technology, who believed it contained an "*exploding pipeline*". Participants also noted the negative perception about the air particles produced. They considered that the CCUS implementation "*needs people to accept it as a part of the solution*". Participants also noted that the public thinks the oil and gas industry is keen on the technology to continue operating business-as-usual, i.e., committing greenwashing. To illustrate their view of the public's perception, participants gave the example of the company "BrewDog[3]" which was under public criticism after it made false climate change mitigation claims.

3.4. Perceived enablers of CCUS implementation

The perceived enablers for CCUS deployment are mainly regional factors. These relate to the favorable context of Teesside, located by the North Sea, and to a supportive Combined Authority (Tees Valley). The Teesside region is also considered unique because it is an integrated cluster (East Coast Cluster) with major emitters located within a 5-mile radius, which contribute to 50% of the UK industrial emissions. Because of this, participants thought there is a relatively high social acceptance for net zero-related projects at Teesside. For example, the production of hydrogen for domestic use was further developed in Teesside (Redcar) compared to other regions because of higher stakeholder acceptance of the technology, despite the project having stalled. The risk of the non-viability of the hydrogen technology in the South due to increased risk of water scarcity was considered an opportunity for its production in the North, leaving CCUS as the most suitable option for the southern industry clusters.

Participants also considered the region benefitted from the Tees Valley Combined Authority (TVCA) to have Net Zero as their "*flag*", with an anticipated the date for reaching net zero of 2040 (instead of 2050). The mayor has been supportive and was supported by the former government (was from same party) and has facilitated public funding (and publicity) for the implementation of net zero technology. Participants noted that the Tees Valley Industrial Cluster was one of the most successful industry clusters with several ongoing investments. They observed that other designated decarbonization industry clusters were not so advanced in terms of implementation or even in the general discussion about the technology as the Tees Valley. They observed that in this region, more people were engaged with the topic, including people in TVCA and organizations in the Tees Valley, than somewhere else they have experienced. The local MPs are also interested in these projects as they believe it can bring economic growth to the region. The mayor has shown leadership in the Net Zero transition and in the support to CCUS and hydrogen technologies. Participants considered, therefore, that local authorities had an important role in promoting and facilitating the technology implementation.

3.5. Perceived factors that would need to be in place to support CCUS implementation

Factors that could further support CCUS implementation in the region are mainly related to the role of UK government in creating a strategy favoring local production of the technology. The participants believed this could entice private investors to invest in the region and to support professional education providers to offer skill and knowledge training.

3.5.1. Development of a reliable UK industry strategy

Participants mentioned that the government vision and type of government makes a difference in the speed of implementation of the CCUS technology. They gave the example of the Middle East where there has been large investment in CCUS by the petrochemicals industry and further highlighted that various governments in the Middle East region have an industrial strategy (and plenty of money) and a COP28 that contributed to increase momentum. Participants suggested to join efforts in the Net Zero transition with integrated industry actions rather than individual actions. Participants believed, for example, that it would be an advantage for the UK net zero strategy to have the production of solar panels and wind turbines located in the UK and not dependent of other countries.

3.5.2. Increased funding/investment

Participants considered that funding is crucial to implement the CCUS technology. They considered that private funding was more

[1]In March 2024
[2]Which has won the elections in July 2024.
[3]https://www.brewdog.com/uk

relevant than public funding because "*there are too many strings attached*" to the latter. By private funding, they meant private investment such as pension funds. Eventually, after further discussion, they recognized that both public and private investment (blended equity, loans, subsidies, government funding, etc.,) was required. Participants considered investment should be longer term rather than dependent of investment cycles. Participants noted that even though private investors were concerned with risk and uncertainty they were also establishing offices in the UK looking for investment opportunities. Participants were also concerned that the level of investment in the technology was different across the globe (e.g., higher in the US and Middle East), and this could undercut the comparative advantage of the Teesside region: "*Big companies in the UK could walk away*".

3.5.3. Investment in skills, knowledge, education, and research

Workshop participants considered that the local availability of skills and knowledge is crucial. They considered the technology is well understood and believed there were many skillful process engineers, with highly transferrable skills. They believed that the existing knowledge on oil and gas exploration and production could bring opportunities for skill transition to CCUS but were concerned that affordable training, including certified continuous professional development (CPD) courses, is not available. One potential advantage of investing in CCUS in the Teesside is the opportunity to export knowledge, skills (and jobs), expertise, and business models worldwide. At the same time, there was still limited knowledge about what are the new business models as well as a lack of clarity on how organizations could join the CO_2 transmission and storage network. Participants considered that the state of technology awareness was not mature enough and pointed out for the limited number of research institutes and universities engaged with the topic through teaching, research, and development. Participants claimed for more funding for MSc and PhD programs and for knowledge exchange.

3.5.4. Positive local attitudes towards the CCUS industry

Participants believed that the public and the people directly involved in the business and industry sectors should have more positive attitudes toward the CCUS technology and should better understand the implementation process. Participants mentioned the case of hydrogen in Redcar and how the domestic hydrogen project had been postponed due to negative perceptions about the hydrogen technology by the local population. They believe that "*social media may influence the perception of CCUS*". On the other hand, they believed that recent events such as the move of the government treasury department to the Tee Valley (Darlington campus) and the creation of the train assembly plant in Newton Aycliffe (Hitachi Newton Aycliffe also known as Newton Aycliffe Manufacturing Facility) were contributing to increase momentum and to boost positive attitudes for the implementation of Net Zero projects (CCUS and hydrogen) in the region.

4. Discussion

Several studies have been undertaken on the public perceptions, attitudes, and acceptance of CCS [9, 14, 20]. However, there is hardly any study focusing on business and industry-related stakeholder perceptions of CCUS. The main aim of this study was to fill this literature gap and to capture the views of business and industry sector managers, engineers, members of staff, and transition technology experts and academics about their awareness of CCUS, on barriers and current and potential enablers for CCUS, and on their and their attitudes towards the technology adoption. The study uses the Tees Valley Industrial Cluster as the case study. It has been assumed that stakeholders from the business and industry sectors are more aware of the CCUS than the public as they are directly involved in the decisions regarding the implementation of the technology. According to Johnson et al. [23], despite the increasing awareness about climate change over the past decades, the public continues to systematically misestimate the technical potential of a wide range of climate change technologies and actions.

This study undertook qualitative data collection through workshops with stakeholders where several questions about CCS and CCU technologies were discussed. The workshops with business and industry stakeholders that were part of this study provide new perspectives on attitudes, perceived risks, and CCUS-enabling elements that have not been covered in other studies. The socio-political challenges to CCUS, for instance, are covered in studies by Fridahl and Lehtveer [24], but this research provides fresh, useful insights into how these barriers appear at the regional level and how local stakeholders view and overcome them. The development of the workshop discussion questions considered the themes retrieved by Jones et al. [7]. These themes focused on issues relating to the general technology concept (*should we do this?*); the technical issues (*can we do this?*); and societal consequences (*what will happen if we do this?*). By discussing questions covering these themes with business and industry-related stakeholders, this study captured three determinants of individuals' intention to perform a behavior, i.e., to adopt or contribute to the adoption of CCU in their organization, as identified by Ajzen [25]. These factors are stakeholders' attitudes towards the technology, their subjective norms, i.e., beliefs about the technology of individuals or groups who are important to them, and their perceived behavior control, i.e., their sense of ability to adopt the technology. Nevertheless, by hosting workshops with a wider range of business and industry-related stakeholders, including experts and academics, rather than only industry staff directly linked with decision-making regarding technology adoption, this study also captured other higher-level factors influencing the intention to adopt the technology, such as the social and economic benefits of the technology for the society (related to "*what will happen if I do this*" and with "subjective norms" from Ajzen [25], the influence of regional context where the case study is located, as well as recommendations on what should be in place to support technology implementation.

It is assumed that Net Zero Teesside offers the opportunity for economic, social, and environmental regeneration of Tees Valley [22]. Stakeholders in workshops were generally supportive of the Net Zero transition and considered that the business and industry sectors should have an active role at contributing to this UK policy goal. They agreed that CCUS should be part of the array of mitigation options implemented to achieve Net Zero. Stakeholders considered that even though the technology is already effective at capturing CO_2 emissions this was mainly a transition technology that would allow time for the development and implementation of other mitigation options. This view differs from Wei et al. [26] who believe that carbon CCUS is imperative for limiting global warming well below 2 °C. On the other hand, Jones et al. [7] came across beliefs that CO_2 utilization would present a remediation of the problem without tackling the source of the problem, with the recognition, however, that it could help to "buy

time" to allow for more efficacious solutions to be developed. In the same line, Offermann-van Heek et al. [27] found experts beliefs that CO_2 utilization was only fighting the symptoms and not the real cause or problem. Interestingly, stakeholders preferred CCU than CCS as they believed the latter would only pass the problem to future generations and was, therefore, considered an intergenerational justice problem. Similarly, Batres et al. [28] report growing concern about the environmental justice implications of related CCUS technologies in the US.

Stakeholders listed several potential benefits of CCUS with some directed at the business and industry sectors only (e.g., to fulfill organizations ESG standards) and others directed at the wider society (e.g., provision of jobs, positive image for the region, enabler of other mitigation options). Employment benefits were also identified by Jones et al. [7] even though with caveats over the number and permanence of these jobs. Within the benefits for the industry and business sectors, participants mentioned that while contributing to ESG standards, CCU would contribute to improve the organization's image and consequently would increase its capacity to attract talented, young workers. Additionally, they considered that adopting green technology would also bring economic advantage. Regarding environmental benefits, participants mentioned that even with their organizational hat on, these should be more important than economic benefits.

While most studies focus on the public acceptance of CCUS as a potential barrier for implementation, this study mainly captured views of individuals working in the industry and business sectors about the barriers for the implementation of CCUS. These were mostly related to their perceived sense of ability to adopt the technology and they were mainly concerned with their limited knowledge and skills about CCUS, the costs of technology, the volatility of the market for captured CO_2, the risks of infrastructure obsolesce, and the political uncertainty about the role of CCUS to contribute to the Net Zero transition. They also believed that negative public perception about the CCUS added extra uncertainty to the existing political uncertainty, consequently slowing down the speed of implementation. This aligns with Fridahl and Lehtveer [24], who consider that low public acceptance could influence politicians' willingness to enact policies for the deployment of CCS. Additionally, Witte [12] corroborates that the lack of regulatory frameworks and political support may influence industrial CCS adoption. In this study, one of the reasons given for public negative acceptance was their belief that businesses and industry wanted to continue emitting business-as-usual and in parallel clearing their image by adopting CCUS, which they considered greenwashing. Jones et al. [7] also reported that participants in his study were doubtful of the technology's suitability to address environmental issues.

Public distrust regarding the industry's ecological motivation [4, 19] or carbonwashing [10], perceived high costs of the technology [29], and the risks of CO_2 storage for health and the environment [4, 19] have been identified as causes of low technology public acceptance. Public acceptance is critical for technology adoption and use [20]. The risk of negative attitudes towards the technology could be mitigated by selecting technological solutions that take the socio-cultural contexts into consideration and by increasing public knowledge of the technology [11].

Despite the barriers mentioned to technology adoption, stakeholders emphasized that the Tees Valley Industrial Cluster was a successful case in progressing CCUS adoption when compared to other industry clusters in the UK. They mentioned that several regional factors such as the proximity between the major emitters, the higher industry and business sector acceptance, and the support of the local authority were the main causes of this success. They recognized that some of the regional advantages may be difficult to reproduce in other areas. One specific regional factor that may also contribute to the general support of CCUS implementation is Teesside industrial past of steel and chemical industry. Gough et al. [17] examined the case of Teesside and concluded that people in regions with a strong industrial base are more positive about industrial CCS development than people who are less rooted in their industrial heritage. Boomsma et al. [30] found that in regions with an industrial heritage, where the local public feels connected to industry, this identity is particularly high and tends to persist even for different industries. They emphasized that CCUS could contribute to increase in the positive image of the region in terms of Net Zero leadership. Imagining adopters as climate leaders was found positive for CCS acceptance in Scandinavia [31].

Finally, stakeholders listed the enabling factors that they thought should be in place to accelerate technology adoption and use. These included the revision of the Industrial Strategy, so it would favor local production of the components required for CCUS implementation, the promotion and attraction of private funding, the investment in training to increase skills, knowledge, and education locally, and finally the promotion of positive local public attitudes towards CCUS via social media. Changing people's perceptions could be achieved with the proactive supply of information by stakeholders, using differentiated communication channels according to the target audience [14, 32]. The differentiation between CCU and CCS should also be made whenever possible, as CCU gathered higher acceptance than CCS among workshop attendants. Factors such as investment in training, policy support, and uncertainty reduction, which is key for organizations to invest in it, were considered crucial by local stakeholders. Arning et al. [19] suggest that communication activities should focus on the CCU potential to relieve the environment, its contribution to climate change mitigation and on its potential to save fossil resources to promote public acceptance. Ultimately, the adoption of the technology is to be undertaken by the business and industry sectors and if the factors enabling it are not established, the technology will not be adopted. Jones et al. [7] noted that CO_2 utilization would have to make economic sense for investors. Whitmarsh et al. [13] also recommend greater collaboration between the CCS and CDU research communities to unify the technologies from a public perception angle. Previous research involving stakeholders has found that policy incentives and political prioritization are essential for the adoption of technology [24]. Further research about the factors hindering technology adoption from the adopters' point of view seems essential, especially in exploring the role of identity. Stakeholders attending workshops seemed to have an environmentalist identity as they considered that business and industry, of which they were part of, should play a key role in climate change mitigation. It was not clear whether this environmentalist identity has been acquired because of the importance placed on Net Zero to contribute to the region's economic growth, or if it was due to a younger generation of staff members in businesses and industry, with different motivations than purely economic. Research has shown that people with a stronger environmentalist identity are more willing to take action to address climate change [33, 34]. It seemed that stakeholders in the Tees Valley had this environmental identity and were actively engaged with Net Zero technologies, contributing to be ahead in CCUS deployment, when compared to other UK industrial clusters. The focus on the Tees Valley's geographical context provides, thus, distinct insights that advance our understanding of CCUS deployment.

5. Conclusion

This study examined industry stakeholder perceptions of CCUS within the Tees Valley Industrial Cluster. The outputs of the qualitative workshops revealed that stakeholders unanimously support their role in climate change mitigation, though they view CCUS primarily as a transition technology rather than a permanent solution. Stakeholders demonstrated a strong preference for carbon capture and utilisation (CCU) over carbon capture and storage (CCS), citing intergenerational justice concerns about passing the problem to somebody else. The perceived benefits extend beyond reduced carbon footprint, including the contributions to meeting the organisational ESG objectives, enhanced ability to attract young workers, provision of indirect jobs, positive regional image, and enablement of other mitigation options such as blue hydrogen production. However, the stakeholders also indicated that significant barriers to CCUS deployment still exist. This included a lack of technical knowledge, high costs and volatile CO_2 markets, political uncertainty and absence of coherent strategy, perceived infrastructure risks, and negative public perceptions framing CCUS as greenwashing. The study revealed that regional factors play a crucial role in deployment success. The Tees Valley benefits from a favourable geographic location, integrated industrial cluster advantages, and strong local authority support, positioning it ahead of other UK industrial clusters. Stakeholders agreed that successful implementation requires coordinated action, including increased investment combining public and private funding, investment in skills and knowledge development, and cultivation of positive local attitudes toward CCUS. This work has demonstrated that successful CCUS deployment depends not only on technological readiness and economic viability but also on understanding and addressing complex social, political, and regional factors that influence stakeholder acceptance and implementation decisions.

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Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The notes collected in the workshops and final report sent to participants are accessible upon request to the corresponding author.

Author Contribution Statement

Diana Feliciano: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Dawid Hanak:** Conceptualization, Methodology, Investigation, Data curation, Project administration, Funding acquisition.

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