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CCUS or no CCUS? Societal support for policy frameworks and stakeholder perceptions in France, Spain, and Poland

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Abstract: Carbon capture, utilization and sequestration (CCUS) is a potentially relevant option to limit greenhouse gas emissions. The development of CCUS has so far been slow in spite of substantial plans for implementation for example by the European Union. Lack of societal support is among the reasons cited for this gap between ambitions and implementation. Against this background, this paper simultaneously looks into the policy framework as well as stakeholder perceptions of CCUS as indicators for societal support. The focus is on three regions in three different European countries (Ebro Basin, Spain; Paris Basin, France; Upper Silesia, Poland) and a potential implementation of CCUS in these regions. The empirical data this paper draws on consists of 40 stakeholder interviews on the regional and national level. Our analysis points to differences between the countries with France being most advanced. The main driver for the development of CCUS in all three countries is (local) economic benefit by preserving existing or creating new industries. Barriers include costs, potential environmental impacts, and to some extent lack of support from policymakers and the public. © 2022 The Authors. *Greenhouse Gases: Science and Technology* published by Society of Chemical Industry and John Wiley & Sons Ltd.

Keywords: Social acceptance; stakeholder perceptions; regional development; carbon capture; utilization and storage; policy framework

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Introduction

Carbon capture utilization (CCU) and Carbon capture and storage (CCS) technologies, summarized by the abbreviation CCUS, are included in many important decarbonization scenarios and policy plans as a significant option to combat climate change for the EU and beyond (e.g., the 2°C scenario 2DS of the IEA[1]). However, development and diffusion of this technology has been slow and is usually below the expectations and plans.[1] Recently, interest in implementing CCUS has been rising again.[2] [a] To play a significant role in future climate change mitigation, CCUS needs to be ready in time, economically viable, and supported by society. In this paper, we focus on societal support of exploring the possible implementation of CCUS as an interplay between (i) social acceptance of CCUS and (ii) CCUS policies. While policy measures that support the deployment of CCUS applications can be diverse (Finon, 2011), some degree of alignment of aims, expectations, and policies on all levels (including the societal perception) appears crucial to achieve the necessary political support (top-down), and to be able to realize the deployment of CCUS (bottom-up). While top down processes are mirrored in political frameworks, measures of social acceptance are an indicator for bottom up support in society. This includes considering the local context which is essential to be able to act in line with the interests and needs of those locally affected.[3] This paper aims to study societal support by combining an analysis of political frameworks and stakeholders' perceptions of CCUS: How far are policy frameworks in place that support the further development of CCUS? What factors influence the deployment of CCUS from the perspective of stakeholders? How far are stakeholder perceptions in line with political frameworks?

To answer the research questions three case studies across Europe are presented from three countries. In each country the European research project "StrategyCCUS" worked on local development plans for a possible implementation of CCUS in selected regions (Ebro Basin in Spain, Paris Basin in France, Upper Silesia in Poland[4]).[b] With the term CCUS this paper refers to the full set of technologies and options to capture CO_2-emissions from industrial processes and either use the CO_2 to produce useful products for shorter or longer term usage or to store it underground.[c] The paper is structured as follows: First we give a summary on the state of research on social acceptance in general as well as a specific focus on the three countries under study. Next the relevant policy frameworks are outlined based on desk research on policy documents and expert input from the project consortium. This includes relevant frameworks on the EU level as all three countries are EU members. Afterwards, stakeholder perceptions on CCUS development are reported based on 40 interviews from representatives from politics and policy, research and education, industry, support organizations and influencers in Poland, Spain, and France as an indicator for social acceptance. Finally, we discuss implications for the implementation of CCUS from our findings for the future of CCUS.

This work differs from previous research in several aspects. First, we take broad view into societal support by combining the policy perspective with stakeholder perspectives. Second, we add to the limited literature of stakeholder views on CCUS considering the situation in three different countries. Stakeholders were selected based on a stakeholder mapping framework that has been carefully developed considering existing frameworks. Third, we contribute to closing gaps in the literature by studying countries less often considered in the research on social acceptance of CCUS, that is, Poland, Spain, and France.

Social acceptance of CCUS

The societal perceptions of CCUS and its social acceptance have repeatedly been subject to research. The next section will provide an overview on the main findings before discussing specific findings from the countries under study.

[a] Since 2017, plans for over 30 new CCUS facilities have been announced, all of them would triple the global CO_2 capture capacity. Furthermore, the investment in 16 advanced projects within the next 12 months is more than USD 27 billion, which is almost twice as much as commissioned in projects since 2010.[2]

[b] The final scenarios can be accessed through the project website: https://www.strategyccus.eu/project-outputs/web-maps/regional-main-scenarios-wp5

[c] Thus, our usage of the term CCUS includes CCS, CCU and CCUS as specified by the IPCC.[52]

State of research

In general, reviews of the studies conducted[5,6] indicated moderate levels of public acceptance, which were neither specifically positive nor negative. However, exposure rates and levels of knowledge were low. It includes that the literature as well as the study participants rarely distinguish between different types of capture technologies or ways of utilization. Low levels of public knowledge have been confirmed by recent surveys in a variety of countries[7,8] as well as by (social) media analyses, which revealed that the discussion mainly takes place in expert circles.[9,10] In comparative studies, CCU, that is, scenarios that foresee some kind of utilization of the captured CO_2, seems to be perceived more positively than CCS[8,11,12] and perceptions of geological storage tend to be the most critical part of the CCUS chain.[13] A few studies have taken a more differentiated view into certain potential application cases of CCUS. For instance, Whitmarsh et al.[8] found that scenarios combining CCS with bioenergy were preferred over CCS in combination with shale gas, underground coal gasification, or heavy industry and Dütschke et al.[13] found preferences for CCS in combination with bioenergy and heavy industry compared to coal-fired power plants has sources from which the CO_2 is captured. Similar findings have been produced by surveys of experts: Romanak et al.[14] found that participants at climate negotiation events were critical of developing CO_2 storage for fossil fuels, but more supportive of its combination with bioenergy. Repeatedly, social acceptance studies have thus concluded that CO_2 storage should be used as the final option when no other alternatives for decarbonization are available[15,16] and as a 'bridging technology'.[5]

Furthermore, there is some indication that certain societal groups, such as the fossil fuel industry, are more open and supportive of the development of CCUS than others, such as environmental NGOs.[16,17,14] Other studies have detected country differences. Based on a small expert sample, Karimi and Komendantova[18] found that acceptance in Germany is perceived to be low and the need for CO_2 storage is questioned, while in the two Scandinavian countries studied, namely Norway and Finland, there are more concerns regarding actual implementation, for example policy support or financial issues. Whitmarsh et al.[8] also found differences between countries based on public surveys, with participants being less positive toward CCS in the Netherlands and more supportive in the United Kingdom and Norway.

Some studies have also explored whether those who are more likely to be affected by nearby CO_2 storage installations differ in their perception of the technology from the wider population. This has led to heterogeneous findings. Several studies found more skepticism towards CO_2 storage on the local level in potentially affected storage areas,[19,20] while Whitmarsh et al.[8] identified the same or higher acceptance levels in local samples in a more recent five-country study (CA, NL, NO, USA, UK), and Terwel and Daamen found that initial reactions to local CCS plans are not necessarily dominated by NIMBY sentiments. Possible explanations for these different conclusions include differences in cultural values[21] or in the structure and history of the energy system.[22]

Due to these opposing views, several case studies have been conducted on social acceptance of existing CCUS projects (cf. summary by[23]). Trust in the developer, the perceived need for the facility, and public engagement activities play a crucial role for the acceptance of real-life projects.[24] The role of communication has been the subject of extensive research[25] and is still identified as a major issue by CCS experts.[26,27]

More generally and as for other technologies, perceived risks and benefits are important predictors of variation in acceptance as outlined in the review paper by L'Orange Seigo et al.[6] on CCS. Following their review, potential risks include leakages or blowouts of CO_2 including induced seismicity, local impacts (e.g., on property value or tourism) as well as CCS representing an unsustainable solution for retaining environmentally harmful industries. On the positive side, the main perceived benefit is the contribution to climate change mitigation, but sometimes also that CCS might enable a smoother transition to a decarbonized society and bring local economic benefits. Recently, the discussion around these potential benefits has been linked to the concept of just transitions and what this implies in the case of CCUS.[22] From a stakeholder perspective, the economics of CCUS as well as regulation and political framework conditions have repeatedly been identified as major hurdles to its deployment.[16,28]

To conclude, even after over a decade of (scientific) discussion around CCUS, it remains an unfamiliar issue for large parts of society as well as for many stakeholders, and support for it is mixed. The larger

part of the research so far has focused on CCS, the body of literature analyzing scenarios including some kind of CO_2 utilization are less frequent in acceptance research. Additionally, and due to the low levels of knowledge and awareness in society, studies usually focus on the general idea of CCU and do not differentiate between different application cases. The few studies doing so find some variations in support, for example the CO_2 source, or whether capture aims to store or use the CO_2. Differences found between countries are likely to be related to cultural and historical conditions as well as the specific energy system and the debate surrounding its transition. This also applies to the local level where projects are planned.

Social acceptance in Spain, France, and Poland

The level of knowledge regarding social acceptance varies in the three countries studied in this paper. In *Spain*, initial research on public and social acceptance of CCS technologies was conducted during the period 2005–2010 in the context of the Spanish PSE-CO_2 project.[29,30,31] Based on a survey of the Spanish population, Solá et al.[31] found very low levels of public awareness about CCS technologies in an early stage of technology development. To coincide with the start of the first two CO_2 storage projects in Spain in 2010–2012 as outlined above, various studies were conducted of public acceptance of CO_2 storage. [24,32,33] Oltra and Sala[32] investigated the public acceptance of CCS technologies and the Compostilla project based on an online survey of residents in the affected region. The survey found a generally positive attitude towards CCS and the Compostilla project (with around 60% of respondents supporting the project and less than 20% opposing the project). More recently, based on survey data from a representative sample of the Spanish population, Sala et al.[34] found a low level of familiarity with CCS, but high interest in it. The initial attitude towards CCS was positive and, after receiving more information about it, the general evaluation of the technology was neutral to positive: respondents were classified as supporters (38%), neutrals (34%) and opponents (28%) of CCS.

Few studies are available on the situation in *France*. One of the few surveys is the 2011 Eurobarometer survey[35] where more than three-quarters of the respondents said they had never heard of CCS technology, while 34% thought it would be effective to fight climate change, and 45% believed that they would not benefit from the use of CCS. The reasons mentioned for not benefiting from this technology included aspects like a possible risk of water pollution. When asked about the safety of a nearby CO_2 storage facility, nearly three-quarters of respondents were concerned due to possible impacts on the environment and health, and possible leaks.[35] A study by Ha-Duong et al.[36] came to similar conclusions.

For *Poland*, internationally published research is even scarcer. There is likely to be a low level of awareness of CCS in Poland's society, but there are no recent studies on this topic. The Special Eurobarometer survey from 2011 testifies to a slightly lower knowledge about CCS in Poland than in other European countries: 77% of the population had never heard of CO_2 capture and storage and only 7% of the population knew what it is.[35]

To the best of our knowledge no study has specifically analyzed CCUS in the three countries from a stakeholder perspective.

Policy frameworks for CCUS

While social acceptance mirrors bottom-up societal support for an innovation such as CCUS, policy frameworks indicate the degree of support from top down. This section outlines the country cases that were examined regarding the implementation of CCUS including the current policies on all levels. First, we present the main policies at the European level as all countries under study are EU members. Then, we provide the policies at national and regional level as well as the country-specific features relevant for CCUS deployment in Spain, France, and Poland.

EU policy

Accelerating the diffusion of CCUS applications in Europe is a key stepping-stone in the strategic energy technology plan,[37] issued by the EU in 2007. The SET plan has the goal of accelerating the transition towards a climate-neutral energy system in the EU by fostering the development of relevant low-carbon technologies. To do so, the SET plan identifies areas where the EU needs to strengthen the cooperation between countries and stakeholders. As one of 10 strategic themes, the diffusion of CCUS is scheduled for the EU to become the global leader in the deployment of renewable energies and carbon zero technology.[38] In line with the SET plan, the directive on the geological storage of

CO_2 (known as the "CCS directive") has established a legal framework for the environmentally safe geological storage of CO_2 as a contribution to combat climate change. This directive applies to all CO_2 storage sites in geological formations in the EU and to the entire lifetime of the storage sites. The CCS directive has been in place since 2009 and had to be transposed into national law by June 2011. In line with the SET plan and the EU's CCS directive, the EU's energy roadmap 2050,[39] states that "for all fossil fuels, carbon capture and storage will have to be applied from around 2030 onwards in the power sector in order to reach the [EU's] decarbonisation targets." This is also in line with the energy union strategy adopted in 2015 (EU 2015), and the European Green Deal policy initiative, which sees CCUS applications as one technology (among others) that can help to "transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050."[40] Policy tools such as the EU innovation fund with a budget of 10 billion euros were established to support low-carbon technologies and are planned to become a major source for funding CCS projects.[41] Detailed regulation such as how different forms of utilization are providing climate benefits as a means to keep CO_2 from the atmosphere are still under development.[42] This is also due to the fact that scientific consensus on measurement approaches etc. is just evolving.

Spain

Over the past 15 years, several CCUS activities and projects have been launched in Spain. The first CCUS activities in Spain were conducted between 2006 and 2012. Two research projects, CENIT-CO_2 and PSE-CO_2, funded by the Ministry of Science and Innovation, initiated the research on CCS technologies in Spain. Hunosa, an energy and coal mining company, built the first pilot plant in La Pereda to test postcombustion CO_2 capture between 2008 and 2012. At the same time, Elcogas built an integrated gasification combined cycle (IGCC) in Puertollano to demonstrate precombustion technology for CO_2 capture. A key project in the development of CCS technologies in Spain was the Compostilla Project (2009–2012), which aimed at demonstrating the full-chain of CCS in Spain, funded by the EU's European economy recovery plan. However, the activities were not continued once the project had expired. A pilot CO_2 storage site was built in Hontomín (Burgos), and an experimental transport installation was built in Ponferrada. Ten years later in 2021, a CCS project is under study in the industrial area of Tarragona in the Ebro Basin as one of the regions studied in the EU-funded research projects StrategyCCUS and PilotSTRATEGY.

Regarding the political framework of CCUS in Spain, although the Spanish national integrated energy and climate plan (NECP) for the period 2021–2030 (Gobierno de España, 2020) considers CCUS an important research area, no concrete policies to promote this technology have been proposed for this period. In the long-term strategy for the period up to 2050 (Gobierno de España. Ministerio para la Transición Ecológica y el Reto Demográfico, 2020), CCUS technologies are considered a necessary option for the decarbonization of industrial sectors that cannot be easily electrified such as cement, iron and steel, and the petrochemical industry. Regarding the regulation of CO_2 storage, the Spanish Law 40/2010 of December 29th on the geological storage of carbon dioxide resulted from a direct transposition of the EU Directive 2009/ 31/CE.

France

France has been active on the CCUS scene since research began at European level in 1993.[43] The results of this initial research were promising in terms of feasibility and safety and paved the way to funding more projects under the EU framework program for research. These projects studied different key aspects in CCUS, from modeling and monitoring methods used to track the CO_2 injected in deep saline aquifers and its potential storage to the prediction of possible long-term effects or the potential environmental effects in case of leakage from an underground reservoir.[43]

CCUS entered France's national policies for climate change mitigation and energy transition in 2009, with different national documents assessing the importance of CCUS to reach the country's goals. The need to work on the implementation of CCS was salient in the national low-carbon strategy in 2015 and in its revised strategy adopted in 2020. In 2017, it was also mentioned in the energy multiannual programming and the national strategy for energy research.[43]

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Poland

In Poland, there have been several programs since the 1990s to support the implementation of CCS projects. For example, KIC InnoEnergy (today EIT InnoEnergy, a European company to support innovations for sustainable energy) and the EU have launched several research programs.[44] In addition, two pilot projects were planned: one at the Bełchatów Power Station, Europe's largest lignite power plant, and the other in Kędzierzyn as part of a "Zero-Emission Power and Chemical Complex". Both projects were cancelled due to insufficient funding.[44,45]

The Polish power mix relies strongly on fossil energy sources. In 2015, 84% of Polish electricity was generated using hard coal and lignite.[46] The ministry of economy therefore described CCS as a possible "Clean Coal Technology".[45] However, the government's attitude towards CCS has been less positive, which became obvious when it implemented the EU directive on CCS in the Polish geological and mining law, which came into force in 2013.[47,45] In this law, Poland decided to allow only offshore demonstration projects.[47,48] Furthermore, a new body was established: the National administrator for underground CO_2 storage sites (KAPS CO_2), which is responsible for, for example, collecting information on the underground storage of CO_2 in order to provide expert advice. To evaluate the CCS projects in Poland, a report is due by the end of 2024. [48,49] Despite the restrictions, CCS is part of the social contract to transform the coal mining sector.[49] However, the energy policy plan for 2040 (PEP2040), which plans to cut coal-fired energy by half, does not mention an explicit CCS strategy.[44]

Stakeholder perceptions of CCUS

As outlined above, specific and recent findings on social acceptance for the countries of interest in this paper are rare. Therefore, we continue with the presentation of findings from an interview study. Given that public awareness on CCUS is likely to be low and as we are interested in societal support more broadly we expected richer findings from interacting with stakeholders.

Methods

To gather input on social acceptance of CCUS, semistructured interviews were chosen as a suitable approach as they provide standardized information to some extent, but also allow topics brought forward by respondents. This paper draws on 40 in-depth semistructured interviews with key CCUS stakeholders in three regions in Spain, France, and Poland.

To identify so called information-rich cases, relevant stakeholder categories at regional and national level were mapped based on earlier conceptualizations of actors in innovation systems,[50] which have been further extended and modified in more recent work to make them applicable for stakeholder identification.[51] The "supply" and "demand" sides form the core of this actor system. When applied to CCUS technology, we suggest that the supply side is understood to demand storage or utilization of CO_2 to discard CO_2 from industrial processes such as heavy industries or electricity generation based on fossil fuels. The supply side thus includes technology providers of CCUS systems along the supply chain from capture technology, through systems to transport CO_2 by different means (trucks, pipelines, ships), up to installations for CO_2 use and storage including injection. The demand side in this case is more complex than for other technologies as it encompasses (1) CO_2 emitters, for example, CO_2-intensive energy generation from fossil fuels and other energy-intensive industry like cement or steel; (2) storage operators; (3) industries using CO_2, for example, the fuel industry or chemical processes that require CO_2. In addition to supply (1) and demand (2), the model includes policymakers (3), research and education (4), support organizations such as finance actors and consultants (5), as well as influencers (6), who include industrial network organizations and environmental groups, for example.

To be able to assess social acceptance and to pinpoint the drivers and barriers that influence the implementation of CCUS projects, selecting interviewees in the key regions aimed at representing all of the introduced categories of stakeholder. Furthermore, participants should be potentially influential in CCUS developments in the study region or be potentially affected by CCUS developments and should have some level of knowledge about CCUS. Relevant stakeholders were found for all the categories. Based on the research design that focused on assessing social acceptance in the three key regions, we will not be able to conduct any cross-regional analyses and foreclose to make statements about national acceptance in the results section.

Interviews were audio-recorded where possible. If this was not the case, the interviewer took extensive

notes of the main opinions expressed by the interviewee during and after the interview. The interviews lasted between 20 and 30 min and were carried out from November 2019 through March 2020. Interviews followed a semistructured format. The following topics were covered in the interview with regional stakeholders: personal overall evaluation of CCUS; assessments of the perceived benefits and costs of CCUS developments in the region; general attitude towards and conditions for acceptance of CCUS developments in the region; perceived barriers and drivers for the development of CCUS in the region; trust in promoters; preference for alternative options; and expectations about the future of CCUS in the region. Details of the interview protocol are shown in Appendix A. The interviews addressed CCUS overall, however, some of the interviews focused on selected parts of the field for example depending on the field of expertise of the interviewee or if for example storage was a major source of concern.

Each of the interviews was coded according to a predefined coding system. The frame mirrored the basic structure of the interview guideline, but the analytic design also allowed for open coding, that is, for new codes arising from the data to be added. The results focused on a thematic analysis that tries to capture and describe lines of arguments and networks of topics from the viewpoint of the study participants and thereby identify patterns that lead to overarching conclusions. In the results section, we structure the findings around *general perceptions, drivers, barriers*, and *acceptance* as well as *future expectations*.

Results

The presentation of our results is structured by countries first, leading to three sections describing the results of the stakeholder interviews in Spain, France, and Poland. Second, we give an overview of the European vision of CCUS. In each section, we present the results based on stakeholders' (1) overall perceptions, (2) identified drivers and perceived benefits of CCUS, (3) barriers to CCUS, (4) the acceptance of the technology, and (5) the expectations about the future of CCUS and comparison with alternative options.

Ebro Basin (Spain)

Overall perception. Most of the stakeholders expected that CCUS technologies would play a relevant role in the decarbonization of the energy and industrial sectors in Spain. Options for CCUS were perceived as more promising in the process industries. The use of CO_2 in the development of products and services was perceived as promising in the long term, but currently insufficient to result in significant reductions in CO_2 emissions. The storage of CO_2 was perceived as potentially problematic due to acceptance issues.

Drivers and perceived benefits. The interviewees mentioned three key benefits of promoting CCUS technologies in the region: the preservation of local industry: "*If this technology is implemented in the medium term, these industries will be able to continue developing their activities*" (E6_R&E); the potential socioeconomic opportunities linked to new CCUS projects (development of new industries, job opportunities and wealth creation); and fostering technological development in the region: "*The main benefit is the possibility to explore a new technology and, if you are able, to lead this technology globally*" (E2_R&E).

The interviewees also identified several enablers for the development of CCUS technologies in the region: the prior existence of process and petrochemical industries potentially interested in implementing CCUS technologies: "*In the Ebro Basin region, we have a powerful industry interested in the use of these technologies*" (E3_Pol). The existence of onshore storage capacity in the region: "*We have suitable areas for deep geological storage of CO_2*" (E8_S&I). The existence of research centers focused on these technologies: "*We have institutions that are very powerful in capture; in technological development, I believe that Aragon is well positioned*" (E6_R&E) (Aragon is an autonomous community in Spain—comparable with a region in England or a Land in Germany).

Barriers. The interviewees focused here on cost-effectiveness considerations. The high price for capturing a ton of CO_2 and the need for important investments in infrastructure (for capture and for storage) were the main costs highlighted. "*There is no doubt that the initial investment is very high. This investment has a very high risk because they are technologies that cannot be considered mature yet*" (E11_Industry). Interviewees also mentioned other costs related to the potential environmental and social impacts associated with CO_2 storage. In this respect,

some interviewees mentioned the potential effects of CO_2 storage on the local environment and potential local opposition as a result: "*In the case of underground storage structures, we would have to see what negative territorial impacts it can have in terms of the environment*" (E3_Pol).

Major barriers mentioned by the interviewees included the low demand for utilization of CO_2: "*Right now, what use does CO_2 have? It has a relatively low utilization. There is no demand for its use*." (E1_S&I), and potential public opposition: "*The general public may oppose this type of project because they think it is not safe to store CO_2*" (E14_Industry). The lack of political and regulatory support was also cited: "*There are legislative barriers, barriers of political support and political uncertainty. There is no legal certainty in this country*" (E8_S&I). Respondents also talked about the distance between storage sites and large emitters and the lack of high emitters in the region: "*The problem with the Ebro Basin is its location, too far from the emitters*." (E1_S&I).

Perceived acceptance. Interviewees were mostly favorable towards the development of CCUS technologies in the Ebro Basin region. Support for the deployment of CCUS in the region was based on a favorable attitude towards CCUS technologies in general as well as on a recognition of the potential benefits of CCUS projects for the region. A minority of interviewees rejected or were skeptical about the deployment of CCUS projects in the region and in Spain in general.

Future expectations and preference for alternative options. Interviewees tended to be more optimistic regarding the medium-term development of small-scale projects of CO_2 rather than big capture and storage projects (perceived as more complex and dependent on political support). For some interviewees, CCUS technologies would complement existing and future renewable technologies. For other interviewees, the existence of alternatives for decarbonization lowers the value of implementing CCUS technologies.

Paris basin (France)

Overall perception. Most of the interviewees thought that the implementation of CCUS technologies would have a relevant role in reducing CO_2 emissions. While some interviewees emphasized that CCU has more potential than CCS, given the perceived limitations of carbon capture and storage (i.e., technical complexity, cost, lack of societal acceptance), other interviewees commented that the use of CO_2 to produce new products and materials is currently very limited, unless technological progress is made. Generally, there was some hope among the interviewees in the Paris basin region that more uses of CO_2 would be developed in the future.

Drivers and perceived benefits. Interviewees outlined some of the benefits associated with the development of CCUS technologies in the region: environmental benefits (reduction of CO_2 emissions), economic benefits (job creation, attraction of new actors, creation of a new industry, potential attraction of investments to the region, and regional leadership in the technology), and other benefits related to companies and the promotion of a circular economy.

Regarding the enablers for the development of CCUS projects in the region, interviewees referred to two main issues: First, they referred to the need for sufficient favorable geological formations in Paris Basin. For example, a regional policymaker stated that they would require that "*there may be some potential for the geological storage of carbon*." (E11_Industry). The second enabler was that that the region is committed to deploy low carbon technology in the region. For example, another policymaker stated, that "*the Paris basin is largely committed to the fight against climate change, in an open and participative way. There is commitment and openness to innovation*." (FR12_Pol).

Barriers. Most of the interviewees referred to important issues concerning economic viability: lack of funding, high costs relative to the cost of emitting CO_2, and low return on investments. Safety considerations were mentioned with regard to the potential impacts of CCS on the local environment (the risk of leakages and health risks). The potential social impacts of underground storage were also a concern for some interviewees. Several interviewees mentioned public opposition to CCS projects in the region since "*CCS can cause a problem if it is installed under vineyards because they are a matter of identity in the region. There is very low social acceptance for this*." (FR2_R&E). Regarding technical feasibility, there was the general perception that France-based industry is technically sufficiently skilled to develop and implement CCUS projects. However, some interviewees were skeptical if

it was right to offer more potential profits to the fossil fuel industry in adopting CCUS technologies and the lack of interest from policymakers.

Acceptance. Most of the interviewees accepted the implementation of CCUS technologies. Interviewees were, in general, positive about the use of CCS along with other low-carbon technologies. The interviewees were positive about the potential benefits of CO_2 applications. Regarding the conditions for acceptance of the implementation of CCUS technologies in the region, interviewees referred to four main aspects: local acceptance, transparency and involvement of civil society, interest from industry (especially those intending to use CO_2), and investments in CCUS that do not compromise investments in other technologies: "*It has to remain proportional: companies should invest x% in CCUS and x% in other low-carbon solutions*." (FR10_Pol).

Future expectations and preference for alternative options. Most of the interviewees thought that CCUS should be part of a broader strategy. CCUS technologies were perceived as part of the solution to climate and energy problems that should be introduced in the medium term: "*What we need is a mix of all the solutions. We have no choice to make, but priorities to define, which are, I think, consumption reduction and renewables. Then, in the medium term*, CCUS" (FR13_S&I).

Overall, there were positive perceptions of the prospects of CCUS in the region. Some respondents thought that there would be CCUS projects in the coming 5–10 years, while others believed that CCUS projects would proliferate in the long term. This positive expectation was usually based on the existence of pilot projects and the existence of active industries in the region. In contrast, other interviewees were more negative about the future of CCUS, based on the existence of public opposition and the expectation that the market for CO_2 use would remain small in the medium term.

Upper Silesia (Poland)

Overall perception. There was a mixed overall perception of CCUS applications in the Upper Silesia region in Poland. While a majority of the interviewees emphasized the importance of CCUS technologies to decrease CO_2 emissions and in the decarbonization in Upper Silesia, others rejected the idea that CCUS should be widely rolled out in Poland. The main concerns surrounded the potential and utility of CCUS technologies, as well the current maturity of the technology, the probable implementation costs, the complex geological formations required as well as the lack of social acceptance.

Drivers and perceived benefits. The coal industry in Upper Silesia is very strong and employs substantial parts of the population. Hence, one of the drivers for implementing CCUS applications is the desire to preserve it by parts of regional policymakers. Other drivers mentioned by the interviewees were increased employment and health benefits for residents. However, since CCUS technology is not well known in the region and the implementation of CCUS applications could lead to contestation, it was stressed that it would be "*important to make people aware that new technologies are not an attack on their future, but a necessary alternative*" (PL7_S&I).

Barriers. Regarding the costs and barriers of deploying CCUS technologies in the region, the interviewees mentioned uncertainties about environmental effects such as the long-term impacts of carbon sequestration and whether there is sufficient market potential for CCU-based products in the region. Furthermore, they anticipated high costs for transport infrastructure and higher energy costs due to reduced power plant energy efficiency. The main barriers mentioned by the interviewees were the lack of financial support and social opposition. A few interviewees also referred to other barriers, such as limited CO_2 storage possibilities, high initial costs of CCUS related to infrastructure investments, doubts whether there are sufficient industrial players to make use of CO_2, and the need to adapt regulations or to pass new laws.

Acceptance. The majority of interviewees were quite positive about the development of CCUS technologies in the Upper Silesia region. For example, it was stated that "*the implementation of CCU technology is acceptable, if it is properly tested, prepared and completely secure*" (PL5_S&I) and that "*CCUS would be acceptable if the security of such storage was guaranteed, and did not exceed economic and social costs*" (PL8_Pol). However, there were also some critical voices that it would be possible that "*storage of CO_2 in coal seams in Upper Silesia may cause great social*

resistance" (PL8_Pol, similar PL12_Industry), and that "*storage is a ticking bomb and society would not be up for it*." (PL8_Pol). While only a minority of respondents were opposed or skeptical about the introduction of CCUS projects in the region, they suggested some conditions (related to costs, infrastructure, public acceptance, and the need for further research and development) that would need to be met for CCUS technologies to be successfully implemented.

Future expectations and preference for alternative options. Concerning the future development of CCUS, a majority of interviewees saw a high probability that CCUS would be implemented in the region. However, the time horizon for this differed among them. While some expected CCUS infrastructure to be implemented within the next 5–10 years, others regard 20–30 years as a more likely time horizon "*due to the high complexity of CCUS related issues*" (PL13_S&I). In contrast to this, other interviewees were not convinced that CCUS infrastructure would be part of the energy-related technology mix in the region, since *"CCUS technologies will prove to be too expensive, too risky, and socially unacceptable*" (PL6_R&E). While a majority of the interviewees anticipated that CCUS applications would eventually be installed, support for alternative ways to remodel the current energy system was also prevalent. These alternative options included renewable energies, nuclear energy, natural gas, the use of green hydrogen, and the better use of energy efficiency measures. Only a few interviewees perceived CCUS as the only option to substantially decrease the CO_2 emissions in the region.

Table 1. Overview of interviewed stakeholders based on the categories of the stakeholder framework.

Stakeholder type	Spain	France	Poland	Total
Politics and policies	2	5	2	9
Research and Education	5	3	4	12
Industry: Demand and supply	3	2	3	8
Support organizations and influencers (NGO's, experts, etc.)	4	3	4	11
Total	14	13	13	40

Discussion

Table 2 provides an overview of the findings from this paper. All the countries studied as well as the European Union have been pushing research on CCUS for more than one decade. In France and Poland, references were even made to the early 1990s. However, the political commitment still varies strongly. While CCUS is part of the climate change mitigation policies in France, and plays a strong role in strategic policy papers including funding for research and innovation activities on the European level, the policy strategy is less clear and partly ambivalent in Spain and Poland.

It is important to keep these framework conditions in mind when interpreting the interview findings on social acceptance in the three countries. In the Ebro region, the interviewees were quite positive and optimistic about the potential of CCUS to contribute to decarbonizing the Spanish economy. It is seen as relevant in the fight against climate change; however, respondents are also very aware of the lack of political support and, thus, expect mainly small-scale developments on a regional level.

The situation is different in the Paris Basin. Again, interviewees acknowledged the relevance of CCUS as an option for climate change mitigation. Overall, significant and positive expectations were voiced for the next 5–10 years. Concerns mainly include those factors mentioned by respondents from all regions: The need to reduce the costs for CCUS including the emergence of more favorable business models, gaining public support in affected regions and transparency and involvement of civil society were also frequently mentioned as an important topic.

Views and perceptions in the Upper Silesia region were mixed. Among the countries studied, it seems to be the one where actual implementation seems least likely or – if it takes place at all – only in the longer term. The country has a restrictive legislative framework, which so far limits CCUS to an evaluation phase and only allows offshore storage. In line with this, stakeholder perceptions were also mixed. However, there were also strong hopes linked to CCUS related to employment benefits and to preserving the country's strong coal industry.

In a direct comparison, France appears to be the country with the clearest and most supportive strategy for CCUS, while Spain is somewhat ambivalent and there are several obvious obstacles for Poland. However, none of the studied regions seems to support the strategies to the same degree. Especially in Spain

Table 2. Overview of CCUS development plans & policies and societal acceptance.

		Spain	France	Poland
CCUS Plans & political framework		- CCS research from 2006 - No actual policies to promote CCUS (2021–2030) - CCUS as a necessary option in the Long-Term Strategy (2050) - Previous research on social acceptance	- Active in CCUS research since 1993 - CCUS in policies for climate change mitigation since 2009 - CCUS saliency in the low-carbon strategy 2015 / 2020 - Previous research on social acceptance	- CCS research activities since 1990 - Strong reliance on coal; CCS as a Clean Coal Technology - Polish Geological & Mining Law (2013): CCS restrictions (offshore) + National Administrator for Underground CCS - No reference to CCS in the 2040 energy policy plan
Societal Acceptance	**Overall perception**	- Seen as relevant for decarbonization - Critical in the long term for process industries; limited for energy sector. - Storage more problematic than use (potential acceptance issues)	- CCUS is seen as part of the solution to climate and energy problems in the medium term.	- The need is generally seen, but there are mixed views on how important it is and at what time horizon CCUS applications are to be implemented.
	Drivers	- Preservation of local industry (E6_R&E) - Socioeconomic opportunities (E2_R&E) - Technological development (E2_R&E) - Presence of process and petrochemical industries (E3_Pol) - Onshore storage capacity (E8_S&I) - Specialized research centers (E6_R&E)	- Potential for of CO_2 emissions reduction (FR4_ Industry, FR13_S&I) - Employment, new industry, investments (FR3_Pol, FR8_Pol, FR9_Industry) - Regional leadership (FR12_Pol) - Favorable geological formations (FR11_Industry) - When regional entities commit to sustainable energy (FR12_Pol)	- Some actors suggest that CCUS can be used to preserve of the strong local coal industry (PL7_S&I). However, there is also opposition to having CCUS applications prolong Polish coal operations (PL1_S&I, PL6_R&E) - Employment opportunities (PL 5_S&I, PL7_S&I) - Health benefits (P13_S&I)
	Barriers	- Cost-effectiveness (E11_Industry) - Low demand for CO_2 use (E1_S&I) - Distance between emitters and storage capacity (E1_S&I). - Potential environmental & societal impacts of CO_2 storage (E3_Pol, (E14_Industry). - Lack of political and regulatory support (E8_S&I)	- High costs, low return on investments, lack of funding (FR2_R&E, FR3_Pol, FR9_Industry, FR11_Pol, FR13_S&I) - Environmental and health risks (leakages) (FR2_R&E) - Local opposition & loss of local identity (FR1_R&E, FR3_Pol, FR10_Pol)	- Long-term environmental effects and uncertainties (P2_R&E P4_R&E, P6_R&E, P13_S&I) - Need for storage in the region to be secure (P4_R&E, P8_Pol) - Transport costs and high investments that may never be recovered (P1_R&E)

(*Continued*)

Table 2. (Continued).

	Spain	France	Poland
Acceptance & general attitude	- Mostly favorable, but doubts about the time frame of introduction and demand for clear policies (e.g. E3_Pol, E7_R&E, E14_Industry) - Hope for potential economic and environmental benefits for the region (E2_R&E, E6_R&E, E7_R&E)	- Mostly favorable attitude towards CCUS applications - CCS should be deployed and utilized together with other low-carbon technologies (FR10_Pol) - Local and national economic (FR2_R&E, FR10_ Pol, FR11_ Pol, FR12_Pol) as well as environmental (FR1_ R&E, FR9_Pol, FR11_Pol) benefits mentioned - However also CCUS being a false solution was mentioned (FR10_Pol, similar FR12_Pol)	- Rather positive (if properly tested, safe, and accepted) (PL5_S&I) - But there is also potential resistance, when old coal seams are used for CCS (PL8_Pol, PL12_Industry)
Future expectations	- Optimism about small-scale and medium-term projects in the region (less dependent on active political support) (E1_ S&I, E12_R&E E13_Industry). - However, CCS is seen as only one option among many others (for example E13_Industry). - CCUS as part of the solution with future renewable technologies, which will depend on the availability of renewable energies at scale (E1_S&I, E4_Pol, E10_S&I).	- Mostly positive about CCUS in the region in the short (5/10 years) or long term and need for a mix of solutions (FR13_S&I). - Conditions for successful implementation are local acceptance (FR1_R&E) transparency (FR8_ Pol, FR12_Pol) and involvement of civil society (FR2_R&E, FR3_Pol, FR8_Pol), as well as interest from industry (FR5_R&E). - Pilot projects and active industries in the region (FR5_R&E). - Concerns related to public opposition and the limited size of the CO_2 use market (FR4_ Industry).	- CCUS will probably be implemented in the region either in the short or the long term (PL13_S&I). - However also voices that are critical due to cost, risk, and potential social unacceptability (for example PL6_R&E) - Preference for alternative – more diversified – options for the region (P4_R&E, P6_R&E, P11_S&I)

and Poland, the national political strategies for the energy transition are not consistent with more ambitious levels on the European level, which makes it less likely that CCUS technologies will be implemented in the next few years.

Quantitatively assessed societal attitudes towards CCUS technology in the studies regions are mostly unknown.[d] The most comprehensive study is the Special Eurobarometer,[35] which was conducted 11 years ago. Since then, Spain has conducted the largest amount of research on social acceptance among the three analyzed countries, which highlighted similar

[d] Recently, the team of authors from this study implemented surveys in France, Spain and Poland which are published in deliverables and an upcoming conference publication:
Oltra C, Preuß S, Gonçalves L, Germán S, Dütschke E. Public acceptance of CCUS technologies. A survey study in France and Spain. Deliverable 3.3. Project StrategyCCUS. 2021. https://www.strategyccus.eu/sites/default/files/D3.3_STRATEGY%20CCUS_Dic_2021_SurveyReport.pdf
Oltra C, Dütschke E, Preuß S, Gonçalves L, Germán S. What influences public attitudes and acceptance of CCUS technologies on the national and regional level? Results from a survey study in France and Spain. Paper presented at 16th International Conference on Greenhouse Gas Control Technologies, GHGT-16, Lyon, France, 23rd -27th October. 2022.

issues to those mentioned in the interviews. Little is known about societal views in Poland, while the available French studies are also mainly outdated. Based on broader literature reviews, it seems likely that very few of those outside specialized communities are aware of CCUS. In the interviews conducted, there were no obvious differences in perceptions between the different application cases of CCUS; however, earlier studies indicated that acceptance for storage is the most difficult to find while acceptance for scenarios aiming at utilizing captures CO_2 seems to be more likely to emerge. It could be the case that such differences are not currently identifiable, as actual implementation of CCUS at scale that goes beyond pilot projects still seems to be rather distant.

The limitations of this paper lie first of all in the limitations of the empirical approach. Findings from interviews are difficult to quantify or to process in order to predict certain or likely levels of acceptance. Furthermore, while they can be used to follow the lines of arguments brought forward by respondents, it is not possible to statistically test relationships between concepts. Thus, it might be interesting for future research to look into differences in acceptance regarding CCU and CCS scenarios or an application for industry only or the energy sector based on more quantitative data. For qualitative studies, the choice of study participants is crucial, as their number is limited and each participant therefore has a strong impact on the findings. For this study, interviewees were selected to cover the CCUS innovation system along a range of categories (see Table 1). It is important to note that representatives from the fields of politics/research/industry dominated our sample, and the views of other communities were less represented. Thus, for example, it is likely that a survey of the general population would lead to different results.

Conclusions

This paper aimed to contribute to closing gaps in the scientific literature concerning social acceptance in relation to the regions studied, and to examine the interplay between regional, national, and European policy frameworks. This combination has the goal to analyze current levels of societal preparedness for CCUS in specific target regions. The paper shows that while the EU has a clear strategy on CCUS, strategies on the national level are less pronounced and have not been translated into regional action programs. Furthermore, while there is some support for CCUS applications, stakeholder perceptions vary between countries which indicate substantial challenges for societal support for advancing CCUS in the mid- and long-term. This includes that the discussion has not advanced to a differentiated view on the various options and pathways summarized by the term CCUS.

If CCUS (or some options in this field) is needed as a further option to mitigate climate change, CCUS applications need to be high on the societal and political agenda. The following recommendations and research angles may contribute to keeping the pathway for CCUS open in the EU. While CCUS has been under discussion for many years now, its progress regarding societal debate and technological implementation has been slow and non-linear. Today, as mirrored in our findings, the situation is still ambiguous and large parts of society are not involved in the debates. For CCUS to become economically viable a strong policy context is needed that incentivizes action on the national and the regional level for example including (higher levels of) carbon pricing. Here similar to Mikunda et al. we suggest that for an accelerated deployment of CCUS policies need to take into account the local context in regions in scope, the heterogeneity of the many types of industrial production processes, as well as the size and location of industrial CO_2 sources. Furthermore, as CCUS is a large-scale technology it needs a broader framework of support – regarding economic conditions but also social acceptance. While the regional level can drive the development by pushing forward pilot projects, the national and European level need to provide the policy framework to it. This calls for a stronger alignment of the strategies as well as a societal debate on the desirability of CCUS in its different options. Further studies of social acceptance seem relevant to develop a better base of knowledge in order to learn more about societal perceptions and how they develop. Here an especially interesting research avenue could be to build a better and more thorough understanding of how CCUS is perceived in comparison to and in relation with other low carbon solutions. Furthermore, it is key to better understand what the barriers are next to stakeholder perceptions on regional and national levels that need to be overcome to accelerate the – so far rather slow – deployment of CCUS applications. When it comes to the implementation of CCUS projects, the study

suggests that engagement processes should be transparent and involving not only local policymakers and industry representatives but also a broader civil society.

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Author Contributions

While all co-authors contributed to a similar extent to implementing the study presented and writing the first draft of the paper. The final editing of the paper was lead by Julius Wesche and Elisabeth Dütschke.

Appendix 1

Interview protocol

For presentation or for the contact letter/email:

My name is _____ and we are conducting this interview as a part of the STRATEGY-CCUS project. The goal of the project is to understand the views of different stakeholders towards the adoption of Carbon Capture, Utilization and Storage (CCUS) technologies in the ____region. As a [type of stakeholder] we value your opinions and insights. We want to know how you personally or your organization feel about CCUS technologies, how do you perceive their potential benefits and risks for the region and whether you think CCUS projects should be supported in your region.
The information collected will be analyzed by the researchers in the project only. We will respect participants' anonymity. In order not to lose any of the information you provide, we would like to make an audio recording of this interview, use this recording as a basis to write a summary of this interview and then delete it.

To inform you about the implications regarding data protection, we prepared this form on informed consent and, if you are fine with it, we ask you to sign it

Introduction

To get started, please let me know about [add an introductory topic about the interviewee] (e.g., history of CCUS in the region, experience with CCUS and the region)

[provide a brief explanation of CCUS to participants not familiar with the technology]

Carbon capture, utilization and storage (CCUS), also referred to as carbon capture, utilization and sequestration, is a process that captures carbon dioxide emissions from sources like coal-fired power plants and either reuses or stores the CO_2 so it will not enter the atmosphere. See https://www.energy.gov/carbon-capture-utilization-storage

General evaluation of CCS and CCUS

- Thinking about climate change mitigation in general, what do you think about Carbon Capture, Utilization and Storage (CCUS) technologies?
- Do you think these technologies can play an important role in mitigation efforts? In your region and in Europe?

Perception of benefits and costs (focus on the region of the interviewee)

Now, thinking about the potential benefits and risks of the adoption of Carbon Capture Utilization (CCU) and Carbon Capture and Storage (CCS) technologies in the region…

[If the interviewee has mentioned any benefits or costs for the region]

- You have mentioned that CCUS technologies would benefit/have this cost…please explain a little more.
- What other benefits do you think this project would have for the region?
- What other negative impacts do you think this project would have on the region?

[If the interviewee has not mentioned any benefits or costs]

- What do you think would be the main (direct and indirect) benefits for the region? Why?
- What do you think would be the main negative impacts on the region? Why?

What other benefits and risks do you think CCUS technologies could have for the region? Elicit potential direct and indirect impacts if not mentioned such as:

Differentiate between *storage* and *use* of CO_2

- Socioeconomic impacts
- Technology development
- Creation of high value products (food preservation, horticulture)

General attitude and conditions of acceptance

- Overall, what is your general position towards the development of Carbon Capture, Utilization and Storage (CCUS) projects in the region? Are you in favor, ambivalent or against such projects? Do you think the adoption of Carbon Capture, Utilization and Storage (CCUS) technologies in the region is acceptable?
- Under what conditions would you accept/reject a project like this? [Explore potential conditions for acceptance or rejection]

Perceived barriers and enablers

- What are, from your perspective, the main barriers to the adoption of CCUS technologies in the region?
- What are, from your perspective, the main strengths of the region for the adoption of CCUS technologies?

Trust in promoters

- Do you think project developers/the industry in the region are/is capable of handling the technical and coordination challenges of adopting Carbon Capture, Utilization and Storage (CCUS) technologies?
- Do you think regional policymakers and the regional administration are capable of handling the coordination challenges of adopting Carbon Capture, Utilization and Storage (CCUS) technologies?
- What about support organizations?
- What about universities and research centers?
- Are there other actors that you consider critical for the adoption of Carbon Capture, Utilization and Storage (CCUS) in the region?

Preference for alternative options

- Do you think there are alternative options to CCUS that you consider better suited to the region in order to substantially reduce CO_2 emissions?

Expectations about the future

- Do you think we will see the development of CCUS projects in the region in the future (next 5 to 10 years)?

Appendix 2

Overview interviewees

Ebro Basin (Spain)

Abbreviation of interviewee	Area of expertise
E1_S&I	Support and influencer organization
E2_R&E	Research and Education
E3_Pol	Politics and Policy
E4_Pol	Politics and Policy
E5_R&E	Research and Education
E6_R&E	Research and Education
E7_R&E	Research and Education
E8_S&I	Support and influencer organization
E8_S&I	Support and influencer organization
E9_S&I	Support and influencer organization
E10_S&I	Support and influencer organization
E11_Industry	Industrial actors
E12_R&E	Research and Education
E13_Industry	Industrial actors (demand and supply)
E14_Industry	Industrial actors (demand and supply)

Paris Basin (France)

Abbreviation of interviewee	Area of expertise
FR1_R&E	Research and Education
FR2_R&E	Research and Education
FR3_Pol	Politics and Policy
FR4_Industry	Industrial actors (demand and supply)
FR5_R&E	Research and Education
FR6_Industry	Industrial actors (demand and supply)
FR7_S&I	Support and influencer organization
FR8_Pol	Politics and Policy
FR9_Industry	Industrial actors (demand and supply)
FR10_Pol	Politics and Policy
FR11_Pol	Politics and Policy
FR12_Pol	Politics and Policy
FR13_S&I	Support and influencer organization

Upper Silesia (Poland)

PL1_R&E	Research and Education
PL2_R&E	Research and Education
PL3_R&Ege	Research and Education
PL4_R&E	Research and Education
PL5_S&I	Support and influencer organization
PL6_R&E	Research and Education
PL7_S&I	Support and influencer organization
PL8_Pol	Politics and Policy
PL9_Industry	Industrial actors (demand and supply)
PL10_Pol	Politics and Policy
PL11_S&I	Support Organization
PL12_Industry	Industrial actors (demand and supply)
PL13_S&I	Support and influencer organization

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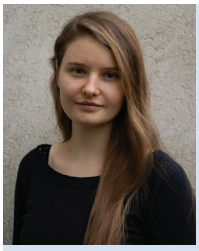

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