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Is there a future for CCUS in Europe? An analysis of the policy framework and societal support

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Abstract

The goal of this paper is to analyse the societal preparedness for CCUS in selected European countries. Societal prepardness is understood as a combined analysis of political and societal perspectives. The countries of analysis include the Netherlands and UK as two frontrunners. Furthermore, Poland, a country currently highly dependent on coal, Germany, Spain and France as highly industrialised countries are included. Overall these six countries are among the highest emitters in Europe. The analysis assembles ongoing activities, the overarching political framework and climate goals; specific regulation and goals for CCUS and existing fundings instruments; the state of knowledge about the public acceptance in these countries. None of the countries seems to be on a straightforward path towards CCUS and especially questions around social acceptance are open in most countries. Most advanced in is probably the UK which combines a favourable regulatory framework with relevant past and recent experiences including high expertise from the oil and gas industry with comparatively favourable perception. The Netherlands have also far developed. In France and Spain some relevant experience are available and regulation has progressed to a certain level, however, the role of CCUS for decarbonisation is not clearly defined in the two countries. Germany and Poland are least developed towards realising CCUS and both miss important enabling regulatory frameworks as well as funding schemes. At the same time, CCUS is vaguley part of political strategies. With regard to social acceptance both countries face challenges.

Keywords: CCU; CCS; support framework; social acceptance; policy alignment; regulatory aspects; societal support

1. Societal prepardness for CCUS

Due to the innovativeness of the technology, the realization of a carbon capture and usage/storage (CCUS) project requires a positive political, legislative and financial support framework along with societal support and acceptance including strategies to bring local citizens on board in affected regions. The political willingness to aim for ambitious climate targets is a pre-condition for providing such a surrounding. This includes setting a legislative framework that prescribes decarbonization and thus allows business models including CCUS to become viable. In addition, legislation regulates the operation of capture, transport and storage sites, a clear framework being highly relevant for operators to know the risks and potential costs related to a project, to know the own responsibilities and responsibilities of others, expectations by the competent authorities and making clear the roles of all participants in the whole project. Although it is to be expected that costs for CCUS activities will fall over time when it moves from being a very innovative first-of-a-kind application to a more mainstream technology, in particular the first-of-a-kind applications require specific support to cover for high costs under high risks. Finally, besides policy support, a number of project developments in

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the 2000s have shown that securing also wider societal support, i.e. public acceptance, is a key pre-requisite in particular for the realization of CCUS projects. While supporting regulation provides legitimization to the technology from a legal point of view, social acceptance is part of the societal license to operate or part of legitimization if the term is used in a wider sense [1]. Social acceptance is defined as the positive response to a proposed or in situ technology or socio-technical system by members of a given social unit such as a country or region [2]. Acceptance has an attitudinal and a behavioral level. The attitudinal level includes the cognitive and emotional response, i.e. how individuals evaluate a technology and how they feel about it. The behavioral level refers to (observable) actions such as decision making, adoption, implementation and usage. Acceptance for an innovation or technology is manifested on the individual and the collective level and these two levels influence each other. For example, social acceptance is usually shared among a bigger group of citizens within a wider region or country; however, it may be rooted in prominently voiced opinions of relevant societal members. In this paper, the focus is on public acceptance and in how far the public supports a further development of CCUS. Current research into social acceptance of CCUS shows that the awareness about the technologies in the broader public continues to be rather limited and that acceptance levels are found to be moderate or neutral on average. It varies in relations to the application case, for example combining coal-fired power plants with CCUS is less embraced by the public than e.g. integration in heavy industries [3]. CCU is evaluated more positively than CCS [4–6]. In the past, community acceptance for CCS was found to be lower than on the national level e.g. for Germany; more recent research in the UK detected also more positive evaluations on the local level [4].

In this paper, we analyze the societal preparedness or readiness [7] for CCUS in selected European countries. Our take on societal preparedness is a combined analysis of political and societal perspectives which we regard as closely intertwined. Our countries of analysis include the Netherlands and UK as two frontrunners in the process of developing CCUS projects. Both countries have far developed support frameworks. We go beyond these pioneering countries and cover a wider geographical area within Europe. Thus, we include further four countries where CCUS is less developed, but may get highly important to reach climate goals in the future due to their economic structure: Poland, a country currently highly dependent on coal, Germany, Spain and France as highly industrialized countries and significant emitters in the EU.

In the following sections, we will cover the countries consecutively starting with currently ongoing activities and the overarching political framework and climate goals. We then move on to specific regulation and goals for CCUS and existing funding instruments. This will be complemented by a summary of the state of knowledge about the public acceptance specifically in these countries. In the end we draw conclusions for the future development of CCUS in these countries. The main methodological approach for this paper consists of an extensive review of the literature including scientific publications as well as policy documents. For the analysis of the acceptance, the emphasis is on academic papers.

2. Policy framework and public acceptance

The countries analyzed in this paper are all EU member states or, in the case of the UK, used to be a member state until recently. Thus, EU policy frameworks are important to them. On the EU level an important mix of supporting policies and instruments for CCUS exists. That includes a long-term vision including three net-zero scenarios for the year 2050 that show an important yet differentiated role for CCUS in the different climate scenarios. The amount of CO_2 captured or reused in the three scenarios lies between 281 and 606 Mt CO_2 in the year 2050. The EU climate law fixes the target for the EU 27 as a group to reach net-zero levels by 2050. With the CCS Directive from 2009, the Commission laid down early on corner stones for the capture, transport by pipeline and particular the storage of CO_2 underground. The CCUS Roadmap to 2030 developed under the CCUS Strategic Energy Technology Plan (SET-Plan)

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provides interim targets such as 15 commercial industrial and 10 commercial power- or heat-related projects [8]. However, there are no larger financial SET-Plan resources to finance the realization of such interim targets and those targets are not binding to Member States or the EU.

Member States partly profit from the EU-based legislations as well as funding, however, additional national support and clarification of the regulatory framework is necessary for the successful realization of CCUS projects. In the following, the implementation of the CCS Directive by a Member State is regarded as a key indicator for the political preparation of a development towards further development of CCUS. Furthermore we look into the distribution of roles in the approval procedures and the operation and closure of transport and storage infrastructure, and analyze the availability and design of additional national financial support instruments.

2.1. Netherlands

The Netherlands is one of the countries of the European Union that decided early on that CCS should play an important part in reaching medium- to long-term climate targets. As a result, three projects had been started, but failed between 2000 and 2017, partly due to acceptance issues [9]. Currently, the Zero Emissions Platform (ZEP) lists a total of eight CCU and CCS projects in the Netherlands and two joint projects on transport and storage between the Netherlands and Belgium. Most significant is the Porthos project in the Port of Rotterdam which was awarded 2.1 billion € from the Dutch government under the SDE++ scheme and receives funding (102 million €) as a project of common interest by the Connecting Europe Facility. The final investment decision for Porthos is pending.

Emissions in the Netherlands lay at around 200 Mt CO_{2e} in 2019 (see EEA GHG data viewer). In May 2019, the Dutch Government adopted its Climate Act which includes the target to reduce emissions by 95% below 1990 levels by 2050. By 2030, greenhouse gas emissions shall be reduced by 49% below 1990 levels. The National Climate Agreement contains information on the sectors' contribution to reaching the climate targets. It states that CCS is an important building block in the decarbonisation of industry (about 7 Mt CO_2 by 2030 could be stored via CCS) and that funding will be provided over an extended SDE+ funding scheme. In the following the regulations will be summarized in a more detailed way as in the other countries as the regulatory support is relatively broad.

In order to implement the CCS Directive, the Dutch Government amended the Mining Act and subordinate legislation (Mining Decree and Mining Regulation) in 2011. The amendments particularly aim at the implementation of the following issues from the CCS Directive [9,10]: (1) Even before the amendments necessary to implement the CCS Directive, the Dutch Mining Act contained a general permit obligation for the storage of substances that included CO_2. The amendments particularly addressed the content of the permit (i.e. the application) and regulations associated with the transfer of responsibility for CO_2 stored after closure of a storage site. The Mining Decree elaborates on the elements that must be regulated in the integral storage permit, including on the risk management, closure of a storage site and financial security. In case of severe leakage or other irregularities, a permit can be withdrawn. (2) The Mining Act was amended to enable the issuance of CO_2 exploration permits. (3) Holders of a storage permit or an exploration permit have the exclusive right to develop activities there. Once the competent authority has received an application for a permit, other parties have the opportunity to also hand in applications for the same storage site. (4) In case of leakage or significant irregularities - in line with the CCS Directive - the operator of a storage site has to notify the competent authority and has to take the necessary corrective measures. (5) Closure is managed by a post-closure plan. In particular, the operator is responsible for monitoring and - if necessary - corrective measures for another 20 years. (6) The Minister of Economic Affairs and Climate Policy is responsible for permit application, inspection of storage sites, dealing with monitoring and liability costs and closure of a site. The European Commission has a consultancy role. With regard to transport and access to transport infrastructure or other details on the transport of CO_2 in the Netherlands are not regulated. Although onshore storage is not forbidden in the Netherlands, as a result of

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public opposition against onshore storage projects in the past the Dutch Government decided to concentrate on offshore storage for the time being (Akerboom et al. 2021).

Regarding financial support, the Dutch Government broadened its support instrument for renewable energy technologies in 2020 to also include emission reduction technologies such as CCU und CCS. Under the SDE++ ("Stimuleren Duurzame Energie") CCU and CCS projects are able to receive a subsidy, paid as a top-up on market prices to eliminate existing price risks. The maximum rate a project is able to apply for is fixed by the Government. In case of CCS projects, the maximum rate is between 62 € /t for existing CCS installations and up to 194€/t in later application phases for new CCS projects in existing installations that are not regulated under the EU emissions trading system (ETS) (2020: 100€/t CO_2 for new CO_2 capture in existing production processes). In the case of CCS projects in installations regulated under the EU ETS, the maximum rate is reduced by the price for EU ETS allowances. In the first call for projects under the broadened SDE++ in 2020, 5 billion € were available for funding, of which 4.7 billion € were being awarded. 2.1 billion € were awarded to CCS projects.

In addition to the SDE++ framework, the Dutch government also introduced a minimum price for CO_2 emissions from industry and power plants that is rising every year. A minimum price of 30€/t CO_2 in 2021, increasing by about 10.50€/t CO_2 per annum, was introduced via the Klimaatakkoord. The minimum price is implemented via a carbon tax reduced by the price for EUAs. In times of lower CO_2 prices under the EU ETS this minimum price can help to keep up the incentive for investments into CCU and CCS projects.

Most research into public acceptance on CCUS in the Netherlands is from around 2010 +/- 5 years. Less is known for the case of industrial CCS and offshore storage as well as recent studies are lacking [9]. One of the few newer papers indicated medium to low levels of awareness and knowledge - higher than in Canada or the US, slightly higher than in the UL and lower than in Norway [4]. Evaluations of CCS were found to be neutral to positive [4,11]. In the multi-country study by Whitmarsh and colleagues [4] the safety of CO_2 transport was found to be a larger concern in the Netherlands than in the UK. Studying what arguments are convincing to the Dutch population, Broecks and colleagues [12] find that normative arguments (for example 'a waste product such as CO_2 should be disposed of properly') or arguments about benefits of CCS for energy production and economic growth are more convincing than arguments about climate protection. As referred to above, three past projects were unsuccessful. The initiative in Barendrecht met strong public resistance and loss of political support [13]. So far, no significant public reaction to the currently running projects has been recorded [9].

2.2. United Kingdom

Similar to the Netherlands, the UK was also quite early on very active in developing CCS projects. Currently ZEP lists 14 CCU and CCS related projects in UK, the CCS project database from the global CCS institute even lists 16 CCU and CCS projects including a Direct Air Capture project. In October 2021, the Government named two CCS clusters which will be funded via the UK CCS Infrastructure Fund (see below): the East Coast Cluster and HyNet. They can now start negotiations with the Government on the specific amount of funding they need to become operational. The goal is to build up a transport and storage infrastructure by mid of 2020.

In 2019, the UK Government committed to reach net-zero GHG emissions by 2050 as recommended by the British Climate Change Committee. Already by 2035 a 78% reduction of GHG emissions below 1990 levels shall be reached. In a report from 2019 by the Committee on Climate Change it is stated that CCUS is regarded as a necessity [14]. The British government's plan for decarbonizing its industry lists CCS as one central point for reaching the net-zero target and aims at a capture capacity of 10 Mt CO_2 annually by 2030 [15].

The Energy Act of 2008 and the Carbon Dioxide Regulations from 2010 provide the basis for CCS activities in the UK and transpose the requirements from the CCS Directive into national law. Storage is allowed in offshore areas

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comprising UK territorial sea and beyond which are designated as gas importation and storage zones under the Energy Act of 2008. Licensing powers, are with the Oil and Gas Authority (OGA) now since 2016. OGA also maintains a carbon storage public register where all UK offshore carbon storage sites are listed. While no CCS project has so far been realized under the existing legal framework, the Scottish Government coordinated a scenario project to test the existing regulatory framework in Scotland (which is quite similar but not identical to the UK also regarding the authorities involved). This led to the conclusion that the legal framework seems to work well, but also highlighted the complexity of the process [16]. In 2021 the Government started a consultation process for the installation of an economic regulation for carbon dioxide transport and storage networks.

While no longer part of the EU ETS, the UK has since 2021 established its own UK ETS, applying similar rules than the EU ETS. CCU and CCS activities are - as under the EU ETS - included and CO_2 that is being captured and stored is exempted from the allowances obligation. In addition, a set of different support schemes is being established in the UK to further support the development of CCU and CCS. Funding will be provided for different areas with differing support systems addressing the particular challenges for the development of technologies in that area: transport & storage (addressing the development of the four planned clusters and more), power, industrial carbon capture, bioenergy with carbon capture and storage (BECCS) and low carbon hydrogen production. Further, in most areas the support instruments include a funding scheme to support up-front investments (mainly grants) and a business model development to support active projects in receiving the required return on investment.

The key instrument to support the development of transport and storage infrastructure as well as for the early development of early industrial capture and storage projects is the CCS Infrastructure Fund [17]. An allocation of 1 billion £ was confirmed in November 2020. The aim of the fund is to develop 2x2 CCUS clusters with the necessary transport and storage network infrastructure. The first two clusters shall be operational by 2025. Further plans and instruments were developed and set up with aim to fund transport and storage business models and to cover revenue gaps. In addition industry CCS project are funded for feasibility and engineering studies or to implement projects. Finally, CCS projects in combination with hydrogen production can be supported under the Net Zero Hydrogen Fund with a volume of 240 million £. In addition, specific business models will also be made available for hydrogen to support the variable costs of production. However, the process is ongoing and more information on the business models is currently not available.

A screening on the literature on public acceptance of CCUS shows that opinions in the UK are often comparatively positive. Multi-country studies find neutral to positive evaluations of CCS, usually more positive than in other countries [4,11]. Nevertheless, at least until some years ago, awareness and knowledge tended to be low [18]; and public discussions are restricted to a niche audience [19]. In parallel, civil society and NGOs are increasingly voicing their scepticism towards the necessity of CCS in a net-zero society [20]. This is related to concerns that the oil and gas industry may delay decarbonisation efforts [21]. Accordingly, support has been found to be dependent on the evolving pathways [22]. Enhance oil recovery is seen critical (probably also a strong intertwinement with fossil fuel industry) [23]. Trust and confidence in actors were found to be key; trust depended on the track record of these actors as well as personal experience [22].

Similarly to the Netherlands, also in the UK before and around 2010 a series of projects failed. Current research found high support in affected areas in surveys [4]. Swennehuis and colleagues [21] suggest that society at large in Scotland is supportive or at least neutral to developments such as the recently ongoing ACORN project. Furthermore, there is also an intertwinement with debates about regional industry transition with pragmatism on the one hand [23] and on the other hand concerns such as that costs for CCS might lead to site closures of the steel industry [24].

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2.3. Poland

Currently, ZEP shows only one CCS-related project in Poland. The project aims at the development of an open access multi-modal CO_2 hub in the Port of Gdansk. In September 2021 HeidelbergCement announced the launch of a new CCS project at the Gorażdże cement plant in Poland under the lead of the Norwegian Sintef Energi AS. The project receives 15 million € funding under H2020.

GHG emissions in Poland were at 380 Mt CO2e in 2019 (EEA GHG data viewer), fourth highest in the EU. For the time being, Poland has not implemented a net-zero target for 2050 yet and has also not formally endorsed the EU's 2050 climate neutrality goal. There are some signs that climate neutrality plays or will play some role on the political agenda by pressure from the regional level and some statements of members of the Polish government. Energy and climate scenarios from independent organisations indicate that CCS, CCU and BECCS could play an important part in the decarbonization strategy of Poland's economy (cf. Kobize, a Polish Think Tank part of the Institute of Environmental Protection - National Research Institute). In October 2021 the Ministry of Climate and Environment launched public consultations on the role of CCS projects in Poland in the future. An attempt to put CCS to the political agenda is the publication of a green paper by an industry group consisting of LOTOS Petrobaltic, LOTOS Group and Azoty Group, representatives of the Polish oil and gas industry as well as a chemical company in November 2021.

In Poland, implementation of the CCS Directive into national law took place in 2013 by the announcement of the uniform text of the Act of June 9, 2011 Geological and Mining law. It solely allows for and regulates the underground storage of CO_2 in order to conduct a CCS demonstration project. Furthermore, only one offshore storage site in the Baltic Sea is currently approved for storage, onshore storage is hence currently banned. By the end of 2024, a report containing an analysis of the projects carried out is to be prepared to present the experience. The national authority in charge of storage projects is the Polish Geological Institute - National Research Institute, who is the National Administrator of Underground Carbon Dioxide Storage Sites (KAPS CO_2). In 2014 (Journal of Laws of 2014, item 1272) the Minister of the Environment issued a regulation on the areas where it is allowed to locate an underground carbon dioxide storage complex and an ordinance on the register of mining areas and closed underground carbon dioxide storage (Journal of Laws of 2014, item 1469). The Regulation of the Minister of the Environment of December 8, 2017 on mining plant operation plans (Journal of Laws of December 11, 2017, item 2293) contains the detailed requirements for the mining plant operation plan required for underground storage of carbon dioxide. In March 2021, the three-year project “CCUS.pl” (Strategy for the development of technologies for capture, transport, utilization and storage of CO_2 in Poland and the pilot of the Polish CCUS Cluster) of Ministry of Economic Development, Labour and Technology began. The project is concerned with the development of a disposal strategy, but may be an opportunity for faster amendment of the law for CCS in Poland.

Currently, there is no national financial support framework for CCU or CCS in place in Poland.

Few studies have been conducted on public acceptance in Poland and partly this research took place ten years ago. The Special Eurobarometer survey from 2011 testifies to a slightly lower knowledge about CCS in Poland than in other European countries (European Commission 2011). An early study by Reiner et al. [25] that was never published as a peer review paper showed positive attitudes towards CCS in Poland in general and on the local level - more positive than in the other European countries surveyed. However, as analysed by Oltra and colleagues [13], an earlier CCS initiative around the coal-fired power plant in Belchatów in Poland met some opposition. More recently, Xexakis and Trutnevyte [26] find negative attitudes for CCS in combination with gas or coal in Poland - similar to their findings in Germany and France.

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2.4. Germany

ZEP currently lists five CCUS projects Germany. Two of them are categorized as CCS in industry, one as CCU in connection with hydrogen and two focus on transport and (short term) storage. All of them with the exception of LEILAC-2 are in early phases and planned to be operational 2023 or later. The latest news from LEILAC-2 one of the CCS in industry-projects refer to completing the PreFEED-report in September 2021 (https://www.project-leilac.eu/latest-news). As in other countries, several initiatives for projects were ongoing in Germany 10-15 years ago including four projects that aimed for storage [27]. Of the four storage projects only one became operational and successfully stored 67 kt of CO_2 in saline aquifer; currently this project is in its closure and monitoring phase. The other three projects failed in the face of public opposition, vanishing political support and loss of interest by the operators from industry [13,27].

Total greenhouse gas emissions in Germany in 2019 were estimated to be 815 Mt CO2e (EEA GHG data viewer, 2021). The country is by far the largest emitter in the European Union. In the year 2021 and following a verdict of the federal constitutional court as well as youth protests the German government decided to aim for climate neutrality until 2045 and implemented this goal in the so called climate protection law. CCUS is so far only considered in policy papers as an option for industries that do not have other options to decarbonize or only at very high costs such in iron and steel production, lime and cement production or in basic chemicals (https://www.bmwk.de/Redaktion/DE/Artikel/Industrie/weitere-entwicklung-ccs-technologien.html). Onshore storage in Germany is currently not considered and the North Sea especially the Norwegian North Sea are mentioned as promising storage sites in policy papers.

The CCS Directive was transposed to German law after long discussions in 2012. The German law merely created a basis for demonstrating carbon dioxide storage on the basis of a few small scale storage projects and set a time frame to start projects until 2016 [28]. The original intention was to evaluate the experiences with the demonstration projects after this period of time, however, no project was initiated. The law that also included an option for the federal states to ban storage in their jurisdiction has not been revised since. An announcement has been made recently to start a process for a societal discussion around CCUS (https://www.bmwk.de/Redaktion/DE/Artikel/Industrie/weitere-entwicklung-ccs-technologien.html).

The German ministry of research abandoned CCS research after the drawbacks a decade ago; however, it initiated a recent program on carbon dioxide removal that partly covers CCS. Some of the broader research programs in Germany such as the energy research program funded by the ministry for economics have enabled some basic research on carbon capture and German institutions have participated in European funded research on the topic.

From beginning, studies showed restraints regarding acceptance in Germany [29] and partly a strong rejection [30]. Recent studies still find a polarization of societal stakeholders arguing for sufficiency, efficiency and consistency instead of implementing CCS [31]. Average citizens show low level of awareness [6] and perceive CCU as more favorable than CCS but - in more recent surveys - that both are acceptable (but not highly) or at least neutral [5,6]. Although there were little activities ongoing, survey studies still find lower levels of acceptance in potentially affected regions [32] and offshore is not seen as more positively than onshore storage [30,33].

2.5. Spain

ZEP currently lists one CCU project in Spain. The project aims at capturing the CO_2 from a cement plant in Carboneras and to recycle the gas for use in the agricultural sector for accelerated crop production. Until 2021, Spain was the only country having an active onshore injection site in the European Union. At the Hontomin Technology Development Plant (close to the city of Burgos) injection of CO_2 and its effects to the surrounding as well as whether

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the CO_2 actually stays underground was monitored. In 2018, it was granted a storage permit for a period of 30 years (10 years to inject a maximum of 100 kt of CO_2 and 20 years for site monitoring) conditional on the environmental bond which was never actually provided by the Ministry of Ecological Transition. At the end of 2021, the Ministry announced the official closure of the storage plant. Hontomin Technology Development Plant was officially recognized by the European Parliament as a key test facility.

Total greenhouse gas emissions in Spain in 2019 were estimated to be 296 Mt CO2e (EEA GHG data viewer, 2021). This makes Spain the fifth largest emitter in the EU. In 2020, the Spanish Government adopted a law to cut emissions to net zero by 2050. The role of CCU and CCS is specified in the documentation to Spain's long-term strategy [34]. The long-term strategy aims at a reduction of emissions by 90% by 2050. The remaining 10% shall be offset by natural sinks to reach carbon neutrality. CCU and CCS are seen to be relevant in particular for the lime and cement production, for the production of fertilizers and in pulp and paper production as well as possibly steel and refineries.

The transposition of the CCS Directive into Spanish law took place in December 2010 by the adoption of the law on Geological Storage of CO_2 (40/2010 Law). The law focuses on the storage of CO_2 and does not regulate transport or capture activities. Further, it explicitly states that planned storage capacity of less than 100 kt is not regulated under this law (in line with the requirements of the CCS Directive), but under Law 22/1973, of 21 July on Mines. Additional amendments have been made for environmental impact assessments, compatibility with the marine environment, integrated environmental authorization, authorization of greenhouse gas emissions under the EU ETS (required for capture, pipeline transport and geological storage of CO_2) and environmental liability. Still missing is a regulatory framework for the permitting process of CCS activities at larger scale.

To our knowledge, currently no additional national funding is available for the development of demonstration projects 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 [35–37]. Based on a survey of the Spanish population, Solá et al. [37] found very low levels of public awareness about CCS technologies. To coincide with the start of the first two CO_2 storage projects in Spain in 2010–2012, various studies were conducted of public acceptance of CO_2 storage [13,38]. More recently, based on survey data from a representative sample of the Spanish population, Sala et al. [39] 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.

2.6. France

In France, currently three CCS projects are being listed by ZEP. In addition, with the K6 Program, France won one out of four CCU or CCS projects funded under the first EU Innovation Fund call for proposals round. The project in the Lumbres cement plant aims at significantly reducing CO_2 emissions from cement production (see https://ec.europa.eu/clima/eu-action/funding-climate-action/innovation-fund/large-scale-projects_en). Some years ago, a CCS pilot-scale project in Lacq-Rousse was operated by Total (2006 - 2013) and injected more than 51 kt of CO_2 during 2010 and 2013 [40].

With 460 Mt CO_{2e} in 2020, France is the second largest absolute emitter in the European Union following Germany (EEA GHG data viewer 2021). Already in 2019, France adopted in its law no. 2019-1147 on energy and the climate the target to become carbon neutral by 2050. Details of reaching this target are specified in the national low carbon strategy. The first version of the strategy was published in 2015 and it was amended in 2020 [41]. Different policy objectives towards CCU and CCS are presented in the document. Sector roadmaps for steel, chemicals and cement

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explicitly name CCS as a lever for decarbonization while no future role is seen for CCS in the energy sector after 2050. CCU is mentioned as a priority area for research.

The CCS Directive has been implemented into national law in 2011 (French national decree on the geological storage of CO_2 - Decree n° 2011-1411). Further legislation relevant is that from 2009 any new coal fired power plant needs to be CCS ready. Already in May 2010 the French parliament had adopted exploration permit principles and granting processes based on the country's mining code, which handles access rights to underground resources. In addition to the approval, injection tests must include public consultations. In France, the Ministère de la transition ecologique is the competent authority dealing with the operation of CCS projects.

Different sources can be accessed for the financial support of CCS projects including support for further research on CCUS [42]. Furthermore, there is support for investments into demonstration projects and for further industrial development. This includes state-aid combining grants and refundable loans or via capital investments by ADEME. The program is however broad also including other types of applications such as water and biodiversity or polluted site remediation. Specific funding programs focusing on CCU or CCS activities were not identified.

Public acceptance in France has rarely been studied and not recently. One of the few surveys is the 2011 Eurobarometer survey [43] 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 [43]. A study by Ha-Duong and colleagues [44] came to similar conclusions.

3. Discussion and conclusion

The aim of this paper was to look into the societal preparedness for exemplary European countries. For our analysis we looked into the current state of development of CCUS as indicated by current and partly by past projects; climate change mitigation goals and thus the likely pressure to head for additional options for decarbonization; the regulatory framework for CCUS with an emphasis on the transposition of the CO2 storage directive and including funding instruments for further research and implementation; social acceptance for CCUS. The countries under study included Netherlands and UK as frontrunners as well as Poland, Germany, Spain and France.

For the Netherlands we find that although plans to realize a full CCS process in the Netherlands are at an advanced stage, no such project has yet been realized. While the Netherlands implemented the European CCS Directive into national law by amending its Mining Act to include important aspects related to the storage of CO2 and access to pipelines, the legal framework still contains a number of uncertainties that could become barriers to the implementation of CO2 pipeline transport and storage sites in the Netherlands, such as costs related to cover for monitoring and unexpected leakage. Other open questions can be expected to be addressed (including the introduction of sufficient legal security) in the process of realizing the first CCS projects in the Netherlands once one of the quite advanced CCS projects come to realization. In the past, CO2 storage in the Netherlands was met by public resistance; overall the Dutch population is on average more aware about CCUS and neutral towards its implementation. Based on earlier studies Akerboom and colleagues [8] argue that a joint communication effort of government, industry and NGOs could improve public perception of CCS.

In the UK, a clear political will comes together with a strong legal framework (based on experience from oil and gas exploitation and other energy market regulations) and with a strong support package. A special feature of the support package is the fact that it includes (mainly grant-based) funding instruments to cover for high up-front investment costs together with business model packages. With the nomination of the two first clusters that will be

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supported and backed by the currently relatively high UK ETS CO2 prices, development of a transport and storage infrastructure along with the development of capture projects could speed up in the coming years. Realization of at least one of those projects will also serve as test for the existing regulatory framework and allow to identify existing shortcomings. In comparison to other countries openness for CCUS pathways and acceptance for their implementation was often higher in the UK. Nevertheless, the discussion is still taking place in niche and the strong intertwinement with the fossil fuel industry has the potential to be a benefit or a downside to the societal debate.

In Poland, a key barrier for the development of CCS projects at the moment is the missing political will. It is unclear which role the Government foresees for CCU or CCS activities and whether the country is actually willing to commit to reaching net zero by 2050. Despite the missing political will and the related missing national support, an announcement has been made for the start of a CCS project in a cement plant in Poland funded mainly by EU sources. This project could be valuable in providing a first test to the legal framework in place. A political restart for CCS could be realized from 2024 when revision of the current legislation is foreseen, although experience with CCS projects by then is very limited. Little is known about public acceptance, however, studies proved low levels of knowledge and some concerns by locally affected population. However, partly the findings are outdated and/or incidental.

Germany has undergone a significant experience with trying to push CCUS forward a decade ago and failed. At the same time the country has highly ambitious goals to become carbon neutral even by 2045 which is especially challenging given that it is the highest emitter in Europe. Until today there is no clear pathway or goal regarding CCUS. It is mentioned as an option for some industries in policy papers. The storage directive has been implemented but is stuck in an evaluation phase. Furthermore, the German government currently excludes on-shore storage and seems to hope for offshore storage under the Norwegian seabed. Public acceptance was very low for past initiatives for CO2 storage with an exception for a research storage site. Offshore storage is not seen as more desirable than onshore storage by the German population. Some survey hint that the negative perception of CCUS may have become more neutral recently.

Despite Spain being one of the first countries of adopting the net-zero target by 2050 in law, CCU and in particular CCS currently are not a key pillar in the Spanish decarbonization strategy. While a role is seen for CCS in the context of some industry sectors, negative emissions are so far solely based on natural sinks and also not coming from the application of BECCS technologies in the available roadmap documents. As a result, there is no clear political dedication and hence no additional national financial support for CCS in Spain. Also, the CCS Directive has been transposed into national law without any further advancements. Hence, shortcomings in the European Directive were taken over into national law. However, a positive aspect for the development of new CCS pilot projects in Spain is the fact that the process of granting an exploration and afterwards a storage permit has been applied once for a test storage site, i.e. some first experience exist with the provision of exploration and storage permits, despite, the fact that the process was not applied on the basis of the CCS Directive but on the basis of mining law as applicable to small storage sites. Studies into public acceptance usually find openness towards CCUS and majorities in favor of CCUS.

In France, although since the increase in ambition of the target to net-zero by 2050 CCS is explicitly mentioned as part of the decarbonization strategy particularly for industry, but also to generate smaller amounts of negative emissions via BECCS, the financial support framework in place so far is not specifically tailored to the needs of CCS projects. Similarly, translation of the CCS Directive into French law took place quite early on, but so far no experience has been gained with the instruments as no projects have been implemented under the framework provided. In spite of a successful and completed CCS project (consisting of capture, transport and geological storage) by TotalEnergies in the South-West of France between 2007 and 2013 (Total 2013), it is not clear that the implementation of the CCS Directive in place is fit for the realization of CCS projects in France at the moment. Very little is known about public acceptance, older studies indicated some concerns in the population.

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Taken together, none of the countries seems to be on a straightforward path towards CCUS and especially questions around social acceptance are open in most countries. Most advanced in this regard is probably the UK which combines a favorable regulatory framework with relevant past and recent experiences including high expertise from the oil and gas industry with comparatively favorable perceptions in the public. The Netherlands have also far developed, but societal support is less clear. In France and Spain the analysis of the regulatory framework as well as the climate goals seem to mirror some interest and windows of opportunities for CCUS, however, the commitment does not appear to be very strong in the two countries. While research into social acceptance indicates that perceptions in Spain might be favorable, little is known about public support in France. Germany and Poland have the least developed strategies regarding CCUS and both miss important enabling regulatory frameworks as well as funding schemes. Thus, significant progress in the next years seems unlikely for those two countries. This conclusion is also supported by some indication that there is lack of public acceptance especially in Germany.

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