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Strategic planning of regions and territories in Europe for low carbon energy and industry through CCUS: the STRATEGY CCUS project

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Abstract

STRATEGY CCUS is a three-year project (2019-2022) funded by the H2020 research and innovation framework of the European Commission. It comprises 17 partners and is coordinated by BRGM (France). STRATEGY CCUS aims to provide realistic strategic plans from 2025 to 2050 for deploying carbon capture, utilization and storage (CCUS) in Southern and Eastern Europe, from a local to a European scale. Eight promising regions, within seven countries are being studied. Plans and roadmaps for these regions will be developed based on economic and environmental drivers, technical potential and social acceptance.

The deployment of operational CCUS clusters starts by an appraisal at local and regional level. Available data for each promising region was mapped to indicate the technical potential of CCUS development in each region. Relevant groups of stakeholders were identified and invited to form Regional Stakeholder Committees within each promising region. These committees are working with project partners to consider regional factors and concerns as well as to elaborate scenarios of CCUS deployment in their respective regions to ensure early local participation. In the 3 most promising regions for the deployment of CCUS, Life Cycle Assessment (LCA), Multiregional Input Output (MRIO) analysis and Techno-Economic Assessment (TEA) designs will provide decision-support for the sustainable development of CCUS. Sound insights and a comprehensive diagnosis of the potential local business models associated with the different CCUS options will be provided for each region, as well as estimates for the sensitivity of the business model on storage capacity and injectivity data.

CCUS roadmaps from 2025 to 2050 for each of the promising regions, with optional connections to existing CO_2 infrastructure in the North Sea, will be elaborated. Scenarios will be based on the available relevant data and carried out in close exchange with the local stakeholders via the Regional Stakeholder Committees and the Industrial Club. Economic evaluation of each scenario will provide the main Key Performance Indicators (KPIs) such as cumulated CAPEX/OPEX required for each scenario, the cost breakdown per CCUS stakeholder, or for example the global costs expressed in €/t CO_2 avoided per scenario. Lastly, an economic impact assessment will be performed at national and European levels in terms of volumes of quotas avoided for industries included in the European Emission Trading Scheme (EU ETS) with the CCUS scenarios and in terms of economic impact on the EU ETS carbon price. Exploitation and dissemination of the project's results and findings engage with relevant end-users (industry and policy makers, local authorities), in order to pave the way for the operational implementation of CCUS clusters. The project is providing targeted information to multiple audiences (including the media and the public) and favoring dialogue, with a public policy perspective.

The systematic approach followed by STRATEGY CCUS will facilitate the appraisal of new other promising regions and the creation of connection among them for the deployment of CCUS Europe-wide.

Keywords: CO2; CCUS; strategic planning; CCUS stakeholders; promising regions;cluster; social acceptance; economic evaluation

Nomenclature

BSA	Boston Square Analysis
CAPEX	Capital Expenditure
CCUS	Carbon Capture Use and Storage
CLSF	Carbon Sequestration Leadership Forum
CTS	Clean Technology Scenario
DSA	Deep Saline Aquifer
DHF	Depleted Hydrocarbon Field
EC	European Commission
EOR	Enhanced Oil Recovery
ETS	EU Emissions Trading System
IEA	International Energy Angency
GDP	gross domestic product
GDPR	General Data Protection Regulation
IC	Industry Club
KPIs	Key Performance Indicators
LCA	Life Cycle Assessment
OPEX	Operational Expenditure
MRIO	Multiregional Input Output
R&D	Research and Development
RSC	Regional Stakeholder Committee
SEF	storage efficiency factor
SET	Strategic Energy Technology
SPE	Society of Petroleum Engineers
SRMS	Storage Resources Management System
t	ton

TEA	Techno-Economic Assessments
TERR	Techno-Economic Resource-Reserve
TRL	Technology readiness leve
WP	Work Package

1. Introduction

The development of CCS has been slow in the last decade in Europe. The European Union's (EU) stated ambition was to have up to twelve operating CCS projects by 2015, however this goal was not accomplished. Only two CCS projects are currently operating in the European Economic Area, Sleipner and Snøhvit, both located in Norway. The main reasons include a low CO_2 price on the EU Emissions Trading System (EU ETS), well below 10€/tCO_2 from 2012 to 2017, although CO_2 ETS price is increasing since 2018, reaching the highest ETS price of 35€/tCO_2[1] on February 1st 2021. Other reasons of the European CCS deployment delay are related to public acceptance for onshore CO_2 storage, the lack of a CO_2 transport infrastructure, concerns about long - term liability, and low societal awareness of this technology.

While slow progress is due to several economic, regulatory and technical challenges, negative perceptions of CCS projects in several nations also played an important role [1, 2]. Projects were set on hold or even cancelled due to reasons such as financing gap, resistance of the local public, or failing to gain or sustain support from political actors [3, 4]. Up to the last decade, the focus was on applying CCS on power generation (mainly from coal), while very little attention was paid to the industrial applications (refineries, steel plants, cement kilns…). And a linear 'point-to-point' CCS development logic was pursued (one CO_2 source, one CO_2 storage, one dedicated pipeline to connect both).

Carbon capture, utilization and storage (CCUS) is a critical part of the industrial technology portfolio. In the IEA Clean Technology Scenario (CTS), more than 28 GtCO2 should be captured from industrial facilities in the period to 2060. CCUS delivers 38% of the emissions reductions needed in the chemical subsector and 15% in the cement industry as well as in iron and steel industry [5].

1.1. STRATEGY CCUS objectives and the promising regions studied

To achieve greater geographical distribution of CCUS clusters within Europe, feasibility studies should consider options in Southern and Eastern European regions - especially those regions that provide the potential for a successful implementation of CCUS. The objective of the STRATEGY CCUS EU-funded project is to develop realistic strategic plans for CCUS development in Southern and Eastern Europe in the short term (up to 3 years), medium term (3-10 years) and long term (more than 10 years). Specific objectives are to:

- Develop local CCUS scenarios, related to realistic and local business models, within promising start-up regions;
- Develop connection plans with transport corridors between local CCUS clusters, and if needed with the North Sea CCUS infrastructure, in order to improve performance and reduce costs, and contribute to build a Europe-wide CCUS infrastructure.

Eight promising regions, within seven countries representing 33% of the European (+UK) industry and energy emissions in 2018 [6], are studied in the STRATEGY CCUS project. They were selected according to criteria relevant for the development of CCUS in Europe: presence of an industrial cluster, possibilities for CO_2 storage and/or utilization, potential for coupling with hydrogen production and use, previous studies already carried out, and a political willingness. They are listed below and illustrated in Figure 1:

1. Paris basin in France (including Paris urban area, Ile de France and Loiret area)

[1] https://ember-climate.org/data/carbon-price-viewer/

2. Rhône valley in France (including the Fos-Berre/Marseille CCU cluster targeted by the EU SET Plan Action 9 (as a Flagship Project), and Lyon metropole)
3. Ebro basin in Spain (including Tarragona industrial area, North Castellón and North Teruel areas)
4. Lusitanian basin in Portugal (including the CO_2 sources in the Leiria -Figueira da Foz axis, and extending to the Lisbon industrial region)
5. Northern Croatia (including Zagreb and the Croatian part of Pannonian basin)
6. Galati area in Romania (including Galati, a port town on the Danube river, and its surroundings)
7. West Macedonian area in Greece (including the Kozani and Ptolemaida industrial areas).
8. Upper Silesia in Poland (including the industrial areas of Katowice, Rybnik and Bedzi)

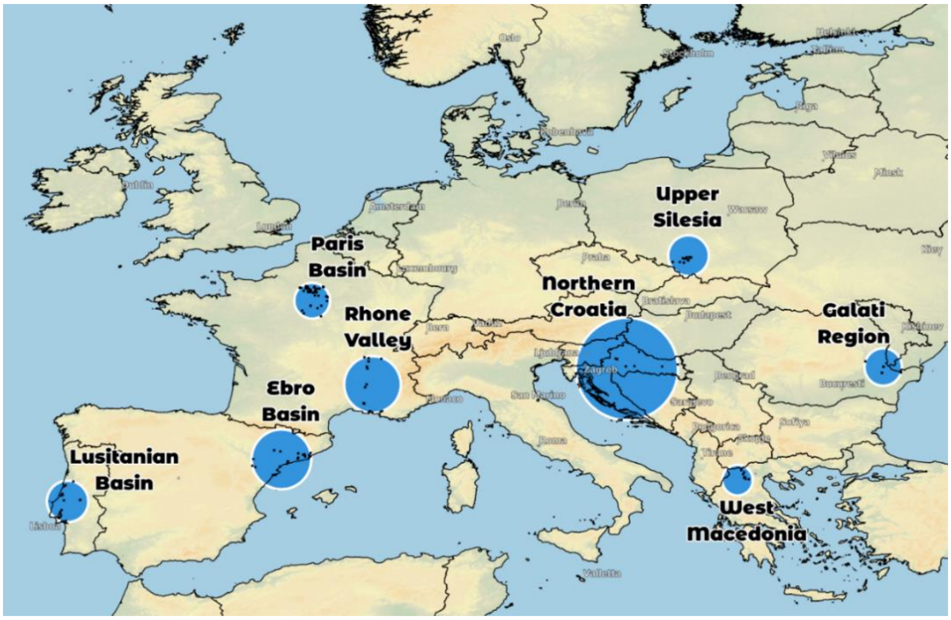

Figure 1: STRATEGY CCUS promising regions in Southern and Eastern Europe.

1.2. Methodology for elaborating CCUS development plans

New CCS schemes are emerging for Europe: the development of CCS hubs and clusters, the importance of regional actions for a global solution and the relevance of early engagement of stakeholders, consideration of CO_2 utilisation options (from CCS to CCUS), connection to H_2 infrastructure, etc. The hubs and clusters approach is indeed the way to progress as in Europe many emissions-intensive industries (industrial and power) are located in tight geographical areas. CO_2 emitters located in close proximity to each other should be linked together to form a ‘capture cluster’ that will supply a shared transport, utilisation and storage network. ‘Storage clusters’ with multiple storage reservoir options are also important considering costs reduction (e.g. relating to seismic acquisition for appraisal and monitoring) and risks management and minimization (e.g. backup storage available in case primary storage does not work, flexibility to expand capacity). CO_2 hubs acting as central collection or distribution points for CO_2 can be located at the end of a multi-user pipeline. Industrial clusters represent a real opportunity to exploit shared infrastructure that many parties can use, therefore benefiting and reducing cost for multiple (and especially small) emitters. They also enable to separate investment decisions (in terms of both time and technology) from the development of the CCUS network. This is important to maximise deployment and exploitation of CCUS and its benefits at scale. Areas where there is a high concentration of CO_2 emitting industries and nearby local capacity to store or use CO_2 can be considered as very suitable for initial hub and cluster developments.

STRATEGY CCUS adopts a bottom-up approach to the construction of roadmaps in the selected promising regions, making first scenarios for CCUS clusters in sub-national regions in order to favor industrial symbiosis and circular economy, and then considering connection of clusters at national and transnational level in a longer term. The current CCUS state-of-play in each of these regions was evaluated following the approach and methodology currently used for CCUS clusters around the North Sea.

In the 3 most promising regions for the deployment of CCUS, the agreed methodology is evaluating impact assessment of carbon life-cycle (LCA), and social-economics factors using MRIO analysis to estimate how CCUS deployment would stimulate the economy and the employment considering the direct and indirect effects.

STRATEGY CCUS carries out cost assessment considering various CO_2 utilisation options in order to improve the business models (e.g. conversion into synthetic fuels using H_2, CO_2 delivery to greenhouses, aggregates, construction materials, CO_2 –EOR etc.). Economies of scale will be sought through industrial symbiosis and shared transport and storage infrastructure. Synergies with other technologies will also be explored, for example with geothermal energy (recovery of heat) and energy storage in connection to power-to-gas processes. Local specifics will be taken into account such as job creation, taxes, and subsidies. Other revenues will include avoidance of ETS carbon quota payments and transactions within the value chain, considering the separation between capture, transport, utilisation and storage liabilities.

In all promising regions, regional stakeholders, including industries, are cooperating in the elaboration of the roadmaps, as they are the first to be affected by changes in their territory. A regional stakeholders committee was set-up for each promising start-up region in order to involve them actively in the construction of the detailed CCUS plans for their region. National and regional surveys will also be conducted to assess the perceptions of the general public.

2. Mapping technical potential of CCUS in the eight promising regions

Each of the promising regions, Paris basin in France, Rhône valley in France, Ebro basin in Spain, Lusitanian basin in Portugal, Northern Croatia, Galati area in Romania, West Macedonian area in Greece and Upper Silesia in Poland, is known to possess specific strengths to implement CCUS, but detailed planning of CCUS clustering and network development requires collecting information at the local level on six groups of technical features relevant to describe the potential for developing CCUS clusters, i.e., i) emissions; ii) area; iii) industry; iv) transport infrastructures; v) storage; and vi) ongoing and potential utilizations for CO_2.

Local teams in each of the regions conducted assessments related to each of the technical features and implemented a methodology to produce a preliminary overview of the technical potential to develop CCUS clusters and networks [7].

The eight STRATEGY CCUS promising regions have identified 174 industrial and power facilities with current CO_2 emissions that amount to 121.5 Mt/y. The Ebro Basin, in Spain, seems to present the most complete set of conditions to deploy the technology, with a diversified industrial sector, in which emission sources are concentrated in a few hotspots of facilities, and with a level of industry integration that seems to be aware and motivated to engage in CCUS. Other regions present also very good conditions for building clusters. It can be argued that the configuration and diversity of the industrial sources in the Rhone Valley is well-suited for defining a network of capture and transport of CO_2. There is here a significant potential for relevant CO_2 utilization options in the chemical sector, for synthetic fuels and for mineral carbonation.

CO_2 utilization is currently very limited, but it can become an important factor for some of the regions in STRATEGY CCUS, at least in the early stages of CCUS deployment. CO_2-EOR should provide the first large scale opportunities in Northern Croatia, where CO_2-EOR is already a reality, but also in the Galati region in Romania. Both the Galati region and Northern Croatia have a good storage potential in well-known depleted hydrocarbons fields, either abandoned or still under production. Scenarios need to calculate the volume of CO_2 avoided, in order to take into account the hydrocarbons which are produced and the fraction of the injected CO_2 that will after some time be produced in the well and reinjected.

Other large-scale CO_2 uses are foreseen in connection to green hydrogen, namely in Portugal, where the roadmap 'Strategy for Hydrogen' relies in the ability to capture large volumes of CO_2 to induce methanation and other chemical processes in order to produce synthetic natural gas and other synthetic fuels (such as aviation fuels). This solution will,however, not be enough to meet all the CO_2 emissions reduction requirements in the region, especially those coming from the process emissions in the cement industry Therefore, geological storage will be a necessity.

Other regions are more monolithic in their industrial structure, with coal-fired power plants being almost the sole responsible for the large CO_2 emissions as in the West Macedonia, in Greece, and Upper Silesia, in Poland. In Greece, a phase-out of coal power plants has been decided, but a CCS-ready power plant is being built. A decision to engage in a CCUS project could become of social relevance to maintain jobs in the coal mining activity in the region.

In Upper Silesia coal mining is also a very important economic activity and implementing CCUS can be instrumental in decoupling CO_2 emissions and coal power plants. The technical context is certainly very good in terms of emissions' volumes and geographical distribution, and positive interaction with industry which is favorable for deploying CCUS clusters in the region. Storage conditions are, nonetheless, far from ideal, with a small storage capacity inventoried so far.

In the Paris basin case a considerable number of Waste-to-Energy plants could provide an opportunity to implement CCUS projects with negative emissions. This region can also benefit from very good storage potential in depleted hydrocarbon fields, able to provide safe conditions for storage while requiring less investments for increasing the maturity of the storage sites.

In total, the storage resources of STRATEGY CCUS regions amount to 8.5 Gt CO_2 of capacity, where deep saline aquifers (DSA) represent ~ 92% of the type of resources and depleted hydrocarbon fields (DHF) around 8% [8]. A potential of 0.33 Gt of CO_2 could be used in North Croatia Depleting Hydrocarbon Fields and in Galati (not counted). The storage capacities reported were calculated using a volumetric approach in most of the cases. In Paris Basin (FR) and Upper Silesia (PL) Saline Aquifers, capacities were estimated through reservoir simulation. Capacity estimate by volumetric approach is dependent on standard parameters (bulk volume, porosity, net-to-gross, CO_2 density) and a modifying term, the storage efficiency factor (SEF). Storage efficiency values also reflect general geologic characteristics and boundary conditions. For example, carbonates and open systems have a higher storage efficiency factor than clastic reservoirs and closed systems. The SEF reflects the level of confidence of storage resources. This coefficient has great impact on storage resources estimate. A conservative approach using a SEF of 2% was applied in regions with low confidence on storage resources classification.

Using a quantitative and qualitative approach to describe storage capacity [9], within DSA and DHF assets, regions reported 60 DSA prospects with 45 described as Tiers 2 (Effective) and 15 as Tiers 1 (Theoretical), and 50 DHF prospects, which are by definition Tiers 2 resources (Figure 2). The Tiers or pyramid approach reflects the increasing maturity of data and understanding about potential storage capacity from regional first approximations to targeted storage site candidates. The requirements for each tier reflect this maturation. The described tiers are compatible with existing schemes (CSLF TERR, SPE SRMS), allowing outcomes to be transferred to equivalent classifications if required.

The type and amount of data used and its quality determine the level of confidence of CO_2 storage resources estimates. A qualitative appraisal of suitability that supports the capacity estimate covers all technical aspects of storage from reservoir capacity and quality to seals, faults and wells. The appraisal consisted of a Boston Square Analysis (BSA) score for both attribute suitability (y-axis) and data quality (x-axis). Therefore, numbers reported for the capacity estimation should be integrated in the CCUS plans taking into account their confidence (uncertainty).

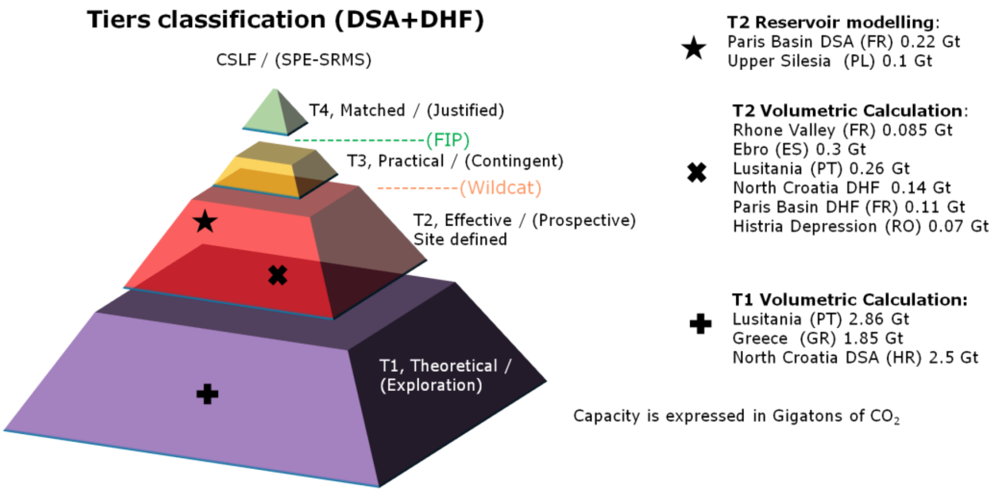

Figure 2: Tiers classification of DSA and DHF assets of the STRATEGY CCUS promising regions. The tiers classificatior represents the total of resources for a region, i.e. the sum of DSA and DHF in this region.

3. Social Acceptance: Stakeholder Mapping and Engagement

Since the diffusion of a technology is not only a technological but also a social challenge, the STRATEGY CCUS project also aims to understand stakeholders' and public attitudes towards CCUS applications. A first identification of the actor structure in the innovation system for CCUS, with a focus on the European level, the national level, and the regional level was performed [10] and served as a basis to prepare further social acceptance studies. Semi-structured interviews with selected members of the stakeholder groups were conducted in each of the regions to identify stakeholders' overall evaluation of CCUS technologies, their level of acceptance of CCUS developments in their regions, sources of concern, perceived benefits and costs of the development of CCUS in the region, conditions for acceptance, perceived barriers and enablers to the development of CCUS in the region and preferences and expectations for energy futures [11].

Building on the results of the regional and national stakeholder mapping, Regional Stakeholder Committees (RSC) were established in each region to provide an opportunity for exchange between stakeholders and the project team and to involve them in the strategic planning of CCUS implementation in the region. Through ongoing cross-sectoral and multi-stakeholder participation, the challenges and opportunities to develop CCUS projects in the regions are assessed.

3.1. Stakeholder Identification

The stakeholder identification and mapping built on a literature review, desk research and exchange with local project partners to identify the stakeholders and a first set of interviews. The literature review showed that the awareness of CCS and CCU technologies in the broader public continues to be rather limited and that acceptance levels are moderate on average. Regarding the local acceptance, the review showed that social acceptance is also influenced by the CO_2 source. Specifically, combining coal-fired power plants with CCUS is less embraced by the public than integration in heavy industries [12]. CCU is evaluated more positively than CCS [13,14]. On a national level, some variety in social acceptance for CCUS was found. In past research, acceptance for CCS was found to be lower on the local than on the national level (e.g. for Germany), however, more recent research in the UK detected also more positive evaluations on the local level compared to the national level [13]. While a few studies have looked into different groups of stakeholders and experts, the majority of social acceptance research focuses on the broader or the local public. Regarding stakeholders, most approaches involved only very small samples and a differentiation between stakeholder categories was therefore difficult to draw.

There are different actor systems which can be modified and applied. The concept of social acceptance, as approached within the STRATEGY CCUS project, allows for a broader perspective on the roles of different actors, their expectations and interactions, and the diverse materialization of technologies at different scales [15]. The core of this actor system are the "Supply" and "Demand" side of the innovation system differentiating groups of actors within these categories. Specifically, the supply side provides the possibility for CCUS, while the demand side produces, uses and stores CO_2, drawing on the technology and service provision of the supply side. The supply side thus includes technology providers for CCUS systems along the supply chain for providing capture technology, installations for transporting CO_2 by different means (trucks, pipelines, ships), installations for CO_2 use and storage including injection. The demand side in this is case is more complex than for other technologies as it encompasses (i) CO_2 emitters, for instance, CO_2-intensive energy generation from fossil fuels and other energy intensive industry like cement or steel; ii) storage operators; iii) the CO_2 use industry, for instance, the fuel industry or chemical processes demanding CO_2. Thus, between these demand side parties also several relationships exist along supply chains. The modified actor system identified six stakeholder categories which can be found on the regional, national and European level: (1) research and education, (2) politics and policies, (3) demand side, (4) supply side, (5) support organisations, and (6) influencers (Figure 3).

To identify and map CCUS relevant stakeholders, a desk research was performed that was informed by a combination of innovation system theories and social acceptance research. It showed that all innovation system related actor groups can be found in the European CCUS innovation system. However, it also shows, that the number of CCUS supply actors is very limited. In some countries, the CCUS related stakeholder density is higher than in other countries. For instance, in Spain, there are a number of governmental bodies that deal with CCUS related topics, while this is seemingly not the case in some of the Eastern and Southeastern European countries. The regional analysis showed that the regions have very different points of departure for the successful implementation of CCUS applications. For example, the regions differ in size, population density, economic development, CO_2 sources and opportunities for CO_2 storage or use respectively. Concerning social acceptance of CCUS applications, the interviews support the findings from the literature review that CCUS is generally a topic that is sparsely touched upon in the local discourse - among lay people as well as in the news media. No earlier social acceptance research could be identified that focused specifically on the regions under study.

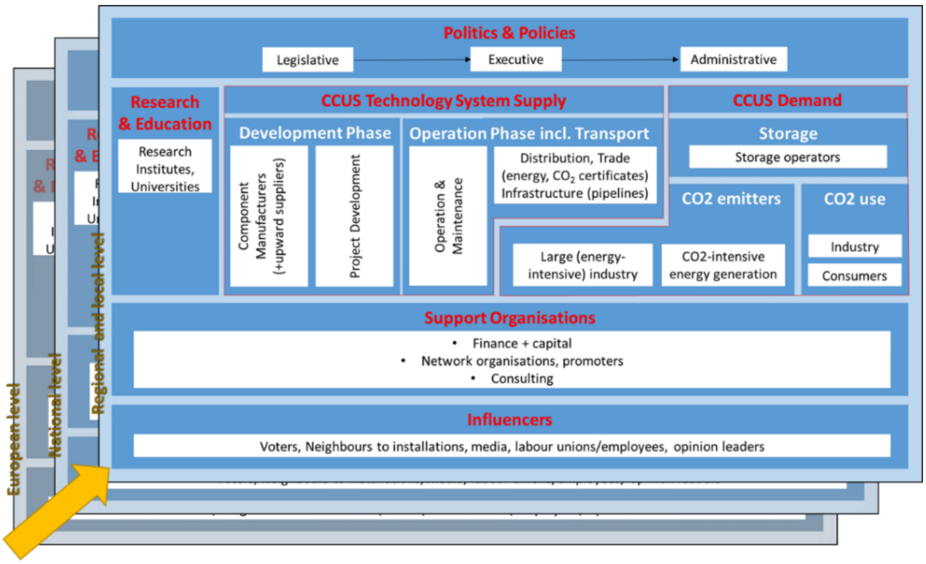

Figure 3: Actors in the CCUS technology system

3.2. Stakeholder views

Both the innovation system of CCUS as well as its social acceptance have been under researched. Thus, the STRATEGY CCUS project aims to extend the perspective on stakeholders and their acceptance concerning CCUS. Hereby stakeholders are defined as a representative of a group that might influence or that might be affected by CCUS developments and therefore has demands and/or responsibilities towards it. To assess the stakeholders' perception of CCUS semi-structured interviews were conducted in each region as well as on the national and European level. Between 10 and 12 representatives of each regional stakeholder group, and additionally around three key informants at the national level, were interviewed in each of the studied regions. In addition, four interviews with European stakeholders were conducted. The first criteria for selection of the interviewees was the maximization of the diversity of stakeholder groups included in the study (Figure 3).

A total of 102 interviews on the perception of CCUS were carried out (Table 1). Participants should be potentially influential in CCUS developments in the region or be potentially affected by CCUS developments and should have some level of understanding of CCUS technologies (alternatively, information was provided to participants before the interview).

Table 1: Types of regional stakeholder representatives that were interviewed in each promising region

Stakeholder type	France (Paris Basin)	France (Rhône Valley)	Spain	Portugal	Croatia	Romania	Greece	Poland
Politics and policies	5	2	2	-	3	2	5	2
Research and Education	3	-	5	3	2	2	5	4
Industry: Demand side (adoption and use)	2	1	2	1	3	5	3	3
Industry: Supply system	-	-	1	1	3	1	-	-
Support organizations	2	4	1	-	2	2	1	3
Influencer (NGO's, experts, etc.)	1	1	3	1	2	3	-	1
Total	13	8	14	6	15	15	14	13

In each of the semi-structured interviews that were conducted in the national language, the following ten aspects were covered: overall evaluation of CCUS, level of acceptance of CCUS implementation in the region, sources of concern, perceived benefits and costs of CCUS in the region, conditions of acceptance, perceived barriers and enablers of CCUS implementation in the region as well as preferences and expectations for energy futures. Most of the stakeholders consulted in the regions considered that the implementation of CCUS technologies would help in climate change mitigation and decarbonisation by significantly reducing emissions in the industry. In countries such as Spain and Portugal, interviewees emphasized the potential role of CCUS in reducing CO_2 emissions from the process industries (cement, steel and glass). In France as well as in other countries, interviewees emphasized that CCUS should be considered as one among many options to reduce CO_2 emissions. Overall, stakeholders have a more favourable attitude towards CCU relative to CCS, although some interviewees perceived CCU as promising in the long term but currently insufficient to result in significant reductions in CO_2 emissions.

Stakeholders in the eight regions outlined the environmental global benefits (climate change mitigation) as well as the potential regional benefits of developing CCUS projects. The socio-economic benefits of implementing CCUS technologies were a key topic of discussion in the eight regions. There was the perception, not shared by all but most of the stakeholders, that CCUS technologies would bring potential regional benefits in terms of job creation and the generation of new industries in the region. As for the potential costs and risks of implementing CCUS in the regions, economic considerations as well as the potential risks for the environment were raised by stakeholders in all studied regions. The societal impacts of carbon capture and storage were also considered by the stakeholders.

Overall, most of the interviewees in the eight regions were rather positive about the development of CCUS technologies. Support for the deployment of CCUS in the regions was based on a favourable attitude towards CCUS technologies as well as on a recognition of the potential socioeconomic benefits of CCUS projects for the region. Only a minority of stakeholder representatives were opposed or skeptical about the introduction of CCUS projects in their region. These interviewees reported a negative attitude towards CCS, preferred alternative technologies to reduce CO_2 emissions and were sceptical about the potential regional benefits of CCUS projects. As conditions for acceptance, interviewees mentioned the need to consider the costs of implementing CCUS (financial viability), acceptance issues (adequate information and engagement), and support from the government (new and adequate legislation).

Regarding the barriers for CCUS deployment in the various studied region, most of the interviewees referred to financial and economic barriers (economic feasibility of CCUS projects), lack of socio-political acceptance and technical feasibility. In Spain, Croatia and Romania, lack of support and interest from authorities, political actors, and administration was considered a critical barrier. Lack of technological know-how as well as limited CO_2 storage possibilities were also barriers mentioned in countries such as Romania and Poland.

Regarding the enablers for the development of CCUS projects, interviewees in the various regions generally pointed to the existence of process and petrochemical industries potentially interested in implementing CCUS technologies as well as to the onshore geological storage capacity.

3.3. Regional Stakeholder Committees

The goal of the regional stakeholder committees (RSC) is to provide an opportunity for exchange between regional stakeholders and the project team and to involve them early on in the strategic planning of CCUS implementation in the region. Through ongoing cross-sectoral and multi-stakeholder participation, the challenges and opportunities to develop CCUS projects in the region are explored. The first RSC workshops in each region took place and two other workshops are planned. Each of the three workshops sets a different focus. The RSC workshops allow attendees:

- To communicate their views (incl. expectations and concerns) and policy needs
- To develop a network of relevant stakeholders that should even live beyond the STRATEGY CCUS project
- To receive information about the STRATEGY CCUS project to act as informants in the region about the project and the CCUS plans.

Each RSC consists of approximately 10-15 relevant and interested key stakeholders that were previously identified. The members of the RSC were contacted and invited by the local partners, in cooperation with the consortium to ensure covering all stakeholder categories identified in the stakeholder mapping (e.g., demand and supply, research and education, politics and policies). The RSC members were provided with different informed consent forms, prepared by the WP-leads, to meet all GDPR requirements. The first RSC workshop was conducted by the local teams in the national language to ensure an optimal environment for discussion. Due to the COVID-19 pandemic, the first RSC workshop took place in a virtual format and provided an overview of the STRATEGY CCUS project and the technologies involved in CCUS to ensure a common basis for all stakeholders. Moreover, additional concerns and barriers on the CCUS implementation (that were not covered in the interviews) were collected from the stakeholders. The first workshop focused on building a common ground and a first exchange for a long-lasting stakeholder network.

4. Methodological developments for mapping environmental and economic drivers

The whole life cycle (LCA) of different CCUS processes to understand and evaluate the various environmental impacts of the production processes is being evaluated for the three most promising regions: Rhone Valley in France; Ebro Basin in Spain and Lusitanian Basin in Portugal. For these 3 regions, a TEA for assessing the costs of various CCUS technologies, and a Socio-Economic Assessments through MRIO analysis will examine the impact of CCUS deployment scenarios on the economy of the regions involved (e.g. gross domestic product (GDP) growth, job creation).

These analyses, LCA, TEA and MRIO aim at providing decision-support for the sustainable development of CCUS in the three selected regions and their integration into a European infrastructure. For LCA, a special attention is given to the consideration of CO_2 flow dynamics, and to incompleteness of process based LCA. For TEA, the analysis will be limited to CAPEX and OPEX estimations. Departing from the scenarios proposed and the TEA estimations, the

MRIO analysis will answer where (in which sectors and regions) socio-economic impacts (both direct and indirect) are originated. Besides, different environmental interactions will also be assessed, such as emissions of pollutants in the air or water consumption, to complement the LCA's detailed results with the completeness of MRIO.

5. Establishing detailed plans for CCUS at different timescales

In order to elaborate realistic economic scenarios of CCUS deployment from 2025 to 2050 for each promising start-up regions of Eastern and Southern Europe, the priority is to look first at local, endogenous, solutions before considering possible connections between regions at national level or crossborders at transnational level. If beneficial, connections to the North Sea CO_2 infrastructures will be considered. A dedicated tool has been developed allowing to assess business case scenarios. From a set of key data collected and the CAPEX/OPEX estimations of different technologies, possible CO_2 hubs and clusters are being defined in each region. These key data include, but are not limited to: identified industrials emitters, tons of CO_2 emitted, maximum existing bankable storage capacities and their characteristics, existing or planned CO_2 transport infrastructures from emitters to storages, existing and planned regional CO_2 re-use options and/or CO_2 - EOR.

For each of the selected regional scenario, an economic evaluation will be performed and discussed with the Regional Stakeholder Committees. As CCUS is a capital-intensive technology it is necessary to quantify cost and potential cost reductions in short, mid, and long-term. A potential for significant improvement exists, for instance, in an adequate sizing of the infrastructures, or from establishing novel low-cost equipment for CCUS technologies.

The economic evaluations of the scenarios will provide economic Key Performance Indicators (KPIs). A set of KPIs (like cumulated CAPEX/OPEX, additional energy cost, total amount of CO_2 avoided, total costs of CO2 avoided or removed, etc.) will be defined for all the scenarios. The economic analysis will evaluate the cost for each scenario and for each industrial installation per ton of avoided CO_2. The transport corridors will consider multiple time scales to identify the most cost-effective development of transport network, starting at the local level and evolving in the short to medium term to national and transnational levels. The costs of transport by pipeline will be estimated based on the amount of CO_2 to be transported from each hub, and the generic design of pipelines, including the pipeline diameter, number of booster stations, and operational costs.

For the purposes of the analysis a set of financial assumptions will be adopted with values relevant with regard to the discount rate, the uncertainty interval regarding costs, the costs of operations, materials, etc. and scenarios for energy prices. National scenarios will be developed from the short to the long term and compared to the greenhouse gases reduction targets of the countries. An economic impact assessment will be performed at national and European level in terms of volumes (and costs) of quotas avoided for industries included in the European Emission Trading Scheme (EU ETS), and in terms of economic impact on the EU ETS carbon price.

6. Expected Outcomes

Results of the first period of the STRATEGY CCUS project include methodology and best practices for CCUS assessment at local scale, as well as methodology and workflow to assess LCA, TEA and MRIO. STRATEGY CCUS revised the current engagement of CCUS technology in seven countries and has delivered outputs to foster the further development of CCUS in these countries using common methodology, defining and sharing standards, key data and challenge issues, enabling an open discussion on the technology and avoiding stranded assets.

The main outputs of STRATEGY CCUS will be: roadmaps at regional, national and transnational scales and social acceptance findings. For each of the eight targeted promising regions, STRATEGY CCUS' outputs expect to accelerate investment opportunities for the deployment of a CCS or CCUS pilot or demonstration project operating in the next 3-10 years, as STRATEGY CCUS will deliver the necessary basis for decision making to prepare a pre-FEED study and to design the infrastructure for hubs and clusters.

The systematic approach followed by STRATEGY CCUS will facilitate the appraisal of new other promising regions and the creation of connection among them for the deployment of CCUS Europe-wide.

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References

[1] Oltra C, Upham P, Riesch H, Boso A, Brunsting S, Dütschke, E, Lis A (2012) Public responses to CO2 storage sites: Lessons from five European cases. Energy and Environment 23:227-248. https://doi.org/10.1260/0958-305X.23.2-3.227.

[2] Anderson C, Schirmer J, Abjorensen N (2012) Exploring CCS community acceptance and public participation from a human and social capital perspective. Mitigation and Adaptation Strategies for Global Change 17: 687-706.

[3] Wallquist L, L'Orange Seigo S, Visschers V, Siegrist M (2012) Public acceptance of CCS system elements: A conjoint measurement. International Journal of Greenhouse Gas Control 6:77-83.

[4] Hammond J, Shackley S (2010) Towards a public communication and engagement strategy for carbon dioxide capture and storage projects in Scotland. Scottish Centre for Carbon Capture Working Paper 2010-08, Edinburgh.

[5] IEA-International Energy Agency. Transforming Industry through CCUS, IEA, Paris https://www.iea.org/reports/transforming-industry-through-ccus. 2019 (aceesed on January, 2021).

[6] EEA-European Environment Agency. Data viewer on projections of greenhouse gas (GHG) emissions reported to the EU/EEA by European countries. 2020 (accessed on January, 2021. https://www.eea.europa.eu/data-and-maps/data/greenhouse-gas-emission-projections-for-7)

[7] Carneiro, J.F., and Mesquita, P. Key data for characterising sources, transport options, storage and uses in promising regions. EU H2020 STRATEGY CCUS Project 837754, Report, pp 146. 2020.

[8] Veloso, F. M. L. Maturity level and confidence of storage capacities estimates in the promising regions. EU H2020 STRATEGY CCUS Project 837754, Report, pp 125. 2021.

[9] Cavanagh, AJ, Wilkinson, M and Haszeldine, RS. Bridging the Gap, Storage Resource Assessment Methodologies, EU H2020 STRATEGY CCUS Project 837754, Report, pp 67. 2020.

[10] Dütschke, Elisabeth; Burghard, Uta; Oltra, Christian; Sala, Roser; Lopez, Sergi (2019): Socio-political acceptance findings. Market Uptake of Solar Thermal Electricity through Cooperation. Available online at http://mustec.eu/node/98, checked on 7/26/2019.

[11] Oltra et al. Stakeholders' views on CCUS developments in the studied regions, report, pp 96. 2020

[12] Dütschke, Elisabeth; Wohlfarth, Katharina; Höller, Samuel; Viebahn, Peter; Schumann, Diana; Pietzner, Katja (2016): Differences in the public perception of CCS in Germany depending on CO 2 source, transport option and storage location. In International Journal of Greenhouse Gas Control 53, pp. 149–159. DOI: 10.1016/j.ijggc.2016.07.043.

[13] Whitmarsh, Lorraine; Xenias, Dimitrios; Jones, Christopher R. (2019): Framing effects on public support for carbon capture and storage. In Palgrave Commun 5 (1), p. 7410. DOI: 10.1057/s41599-019-0217-x.

[14] Linzenich, Anika; Arning, Katrin; Offermann-van Heek, Julia; Ziefle, Martina (2019): Uncovering attitudes towards carbon capture storage and utilization technologies in Germany. Insights into affective-cognitive evaluations of benefits and risks. In Energy Research & Social Science 48, pp. 205–218. DOI: 10.1016/j.erss.2018.09.017.

[15] Devine-Wright, P.; Batel, S. (2017): My neighbourhood, my country or my planet? The influence of multiple place attachments and climate change concern on social acceptance of energy infrastructure. In Global Environmental Change 47, pp. 110–120. DOI: 10.1016/j.gloenvcha.2017.08.003.