STRATEGY CCUS
A viable solution for a sustainable future

Public Final Report

STRATEGIC PLANNING OF REGIONS AND TERRITORIES IN EUROPE FOR LOW-CARBON ENERGY AND INDUSTRY THROUGH CCUS

Release Status: FINAL

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Date: 31 August 2022

Filename and version: D1_4_Public_FinalReport_31082022.docx

Project ID NUMBER 837754

STRATEGY CCUS (H2020-LC-SC3-2018-2019-2020/H2020-LC-SC3-2018-NZE-CC)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Document History

Location

This document is stored in the following location:

Filename	D1_4_Public Final Report
Location	https://www.strategyccus.eu/project-outputs/project-management-outputs

Revision History

This document has been through the following revisions:

Version No.	Revision Date	Filename/Location stored:	Brief Summary of Changes

Authorisation

This document requires the following approvals:

AUTHORISATION	Name	Signature	Date
WP Leader and co-leaders	WP2; WP3; WP4; WP5 and WP6		30/08/2022
Project Manager	Frédérique Mojon Lumier		31/08/2022

Distribution

This document has been distributed to:

Name	Title	Version Issued	Date of Issue
		PUBLIC	00/00/0000

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Veloso et al. 2022. D1.4 Final Project summary. Deliverable of EU H2020 STRATEGY CCUS Project. Grant Agreement 837754.

STRATEGY CCUS project DOI: 10.3030/837754.

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Executive summary

STRATEGY CCUS project elaborated strategic plans for the deployment of CCUS in eight regions of Southern and Eastern Europe – Paris basin and 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. The institutions representative of their region – local teams – carried out an exercise of mapping, modelling, consultation and analysis of why, how and when CCUS would integrate the industrial landscape of their regions and country for some regions. Local teams were guided and assisted by experienced partners, the supporting countries: Germany, United Kingdom and Norway.

A common methodology led local teams in the regional mapping of technical aspects as industrial clusters identification, transport network options, storage resources and CO_2 utilization possibilities. This first picture of regional technical aspects provided elements to start discussions about CCUS plans with regional and national stakeholders, the Advisory Board, and the Industry Club. The Advisory Board and the Industry Club are representative of institutions, associations, industries and experts with know-how in CCUS technology or in some other elements involved in the CCUS chain. STRATEGY CCUS Regional Stakeholder Committee are comprised by 10 to 15 persons representative of relevant stakeholders in each study region, including industry associations, environmental NGOs, local and central government, expert researchers in the field, media, etc. A previous literature review and regional interviews identified the profile of educated guess on CCUS technology who assisted local teams in the elaboration of CCUS strategic plans through project workshops.

In the eight STRATEGY CCUS regions, a total of 174 industrial and power facilities were mapped that amounted to 121.5 Mt of CO_2 emission per year in 2017. Regional storage resources equated to 8.5 Gt of capacity with ~92% in Deep Saline Aquifers (DSA) and ~8% in Depleted Hydrocarbon Fields (DHF). Although regions presented a high potential of geological storage capacity, these estimations are mostly immature prospects with low confidence. Indeed, resources are classified as Tiers 1 (basin scale estimation) and Tiers 2 (site estimation) when geological resources are considered as commercial or ready to operation they are classified as Tier 3 (drilled appraisal well) and Tier 4 (injection test completed).

Regional scenarios are based on National Low Carbon (or carbon neutral) Strategies and have been built by the eight regional teams. For each regional team to carry out a techno-economic evaluation of their regional CCUS scenarios, a dedicated technical and economic evaluation CCUS scenario tool (STRATEGY CCUs Tool) has been developed in the project by the project partners. This techno-economic tool evaluates the CCUS scenarios from 2025 to 2050 and was made available to all teams.

Based on the trend emissions of large emitting industrial facilities, their difficulties in reducing CO_2 emissions, and their potential sectoral commitments to CCUS technology, candidate industries were selected to develop regional CCUS scenarios. In parallel, the maximum regional and annual CO_2 storage capacities were considered so that the emissions captured annually could be transported to these regional storage capacities.

One of the final objectives of the techno-economic evaluation of the CCUS scenarios is to determine whether there is a financial incentive (or not) to invest in CCUS relative to the costs of compliance with the EU ETS, at least what is anticipated in the future in the project. Total cost of CCUS were compared to the total costs of compliance with the EU ETS to see the difference between the two.

Of the eight regions evaluated, the top three regions where CCUS is more attractive than EU ETS compliance are (1) Upper Silesia (4 302 M€ of lower costs with CCUS compared to EU ETS costs), followed by (2) Paris Basin (1 411.9 M€), and then Northern Croatia with 1109.5 M€ of financial gap.

In two regions, which are Ebro Basin and Lusitanian Basin, it is financially more attractive to pay the EU ETS compliance costs than to invest in the CCUS. But in environmental point of view the Ebro Basin and Lusitanian Basin allow to avoid respectively 66.3 and 60.2 $MtCO_2$.

It should be notice that these results are highly influenced by the EU-ETS scenario price.

At the end, for the eight regions, the share of CO_2 avoided through CCUS in the national greenhouse gas reduction strategy in 2050 varies from 9% for Western Macedonia, the Rhone Valley, and the Paris Basin for the lowest, to 33% for the Ebro Basin region, 43% for the Upper Silesia region, and 66% for the Lusitanian Basin which is the highest.

Across the eight regions, nearly 78% of the CO_2 captured is ultimately avoided taking into account the CO_2 released to the atmosphere in fast-moving consumer goods (like e-fuels). The amount of CO_2 avoided (357 Mt) in the eight regions is greater than the amount of CO_2 stored (343 Mt) due to the long-term use of CO_2 in mineralization (Western Macedonia and Ebro Basin). When $bioCO_2$ is captured and stored in geological reservoirs or used in long-lived products such as mineralization, it may be considered a negative CO_2 emission.

In average, OPEX costs contribute 63% of total CCUS costs and are mainly energy consumption. These expenses should be reduced as main priority to reduce the cost of the CCUS chain and CO_2 emissions associated.

Capture costs, for industries other than power plants are high. This has a significant impact on the costs of the entire CCUS chain (capture costs generally represent a significant portion of total costs – 32% in average). Capture costs for CO_2 intensive industries other than power plants must be reduced in the future to limit the costs of the CCUS chain.

The pooling of investment costs, particularly infrastructure costs, makes it possible to reduce the costs of the CCUS chain. Planning for the transportation and storage infrastructure needed to deploy CCUS over the long term is necessary.

A real challenge of scenarios is to match estimated storage capacity with accumulated emissions during the period of CCUS deployment between 2025 and 2050. Upper Silesia (PL) and Rhône Valley (FR) are high emission regions with insufficient local geological storage resources. An attempt of building transnational scenarios showed how it is possible to increase the quantity of CO_2 captured through cross-border transport of CO_2 to regions with greater storage capacity, thus confirming storage capacity as one of the strong limiting parameters for the development of scenarios.

A case study in Portugal analysed the benefit of disaggregating the CCUS network in sub-systems of minor scale to launch CCUS technology. The choice of facilities is a key factor to decrease costs that are mainly related to CO_2 capture. These sub-systems would connect large infrastructures at national scale in a second period, which alerts us to the need for long-term planning for CCUS infrastructures deployment.

The CCUS scenarios developed in the frame of the STRATEGY CCUS project are meant to help decarbonize the economy by cutting direct CO_2 emissions and valorising or storing them. The net drop in greenhouse gas (GHG) emissions of these scenarios needs to account for potential indirect environmental effects. Life cycle assessment (LCA) performed in Rhône valley (FR), Lusitanian Basin (PT) and Ebro Basin (ES) demonstrated the impact of capture process (mainly related to energy provision) as the most critical contributor to generated GHG emissions and significantly to Cumulative Energy Demand (CED). The storage of biogenic CO_2 occurring in some regions implies negative emissions which are determinant in the global GHG balance. The impacts of CO_2 utilization strongly depend on the final use of CO_2 and on the transformation process settings (e.g. renewable power consumption for energy needs). In these three regions, Multi-Regional Input-Output analysis (MRIO) assessed socioeconomic benefits of CCS deployment. CCS would create 276,200 full time equivalent (FTE) jobs up to year 2050, both direct and indirect. That is approximately 11,050 permanent jobs. In three regions, the employment retained would be 203,300 FTE jobs (74%), or 8,130 permanent jobs.

A final synthetic analysis of the possibly way forward for CCUS deployment in the 8 regions identified main issues in STRATEGY CCUS regions. The summary divided into three large groups: techno-economic, social and policies, and government factors highlights issues of these key pillars for deploying CCUS. Business model and cost (mainly related to capture system and OPEX), maturity of storage, establishing good social awareness, policies, incentives and working with clarifying the regulations for CO_2 storage appear as cornerstone for enabling CCUS value chains across Europe.

STRATEGY CCUS launched a regional dynamic on the feasibility of CCUS technology in eight territories of seven EU countries. This first exercise of planning CCUS scenarios showed the benefits of taking in consideration local and regional technical aspects, as well as needs and concerns of stakeholders. At this stage, stakeholders are national and regional educated guess about CCUS technology and are concerned directly or indirectly if CCUs is deployed. The PilotSTRATEGY project, sequel to this one, a 5-year H2020 RIA project[1] led by BRGM and embarking various STRATEGY CCUS project beneficiaries is making an important step in the feasibility of STRATEGY CCUS scenarios. Using results of its sister project, PilotSTRATEGY will increase the maturity of storage resources, five Deep Saline Aquifers already identified as potential geological storage sites, in five STRATEGY CCUS regions: Paris basin, Lusitanian basin, Ebro basin, West Macedonia and Upper Silesia. PilotSTRATEGY will keep the local dynamic created by STRATEGY CCUS within stakeholders while enlarging and targeting stakeholder profiles to include general public and municipalities.

[1] The PilotSTRATEGY project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101022664. https://pilotstrategy.eu/

One of the major challenges of STRATEGY CCUS, a Coordination and Support Action H2020 project, was to share and disseminate project findings and results. This mission is important to inform and raise awareness on CCUS technologies and issues among stakeholders at all level and the public at large. During the project life a variety of communication tools and resources were developed and made available mainly on the project website, in support stakeholders communication and engagement: public webinars, reports, several newsletters, dynamic web maps, a stakeholder toolbox, project brief in respective local languages…. All are available on the project website[2].

Toward the end of the project, specific events were organised at regional level, supported by local partners and promoted on the project social media, mainly to inform targeted public and regional stakeholders on the project outputs and in particular local scenarios developed during the project.

To address decision makers at European level, the consortium held a Final Event in Brussels (and also online) on June 14-15, 2022, with 200 participants from the industry, environmental organisations, academia and other projects leaders who came to share their own experience in the deployment of CCUS technologies. Enriching discussions followed involving European MPs and other decision makers about the way to convert the try, stepping from results to actions and the required policies, regulations and incentives to promote the impact of results and further development at European scale with the support of key-stakeholders.

[2] https://www.strategyccus.eu/

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1 Project Overview

1.1 Introduction

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, utilisation and storage (CCUS) in Southern and Eastern Europe, from a local to a European scale.

Eight promising regions, within seven countries representing 33% of the European (+UK) industry and energy emissions in 2018, 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 utilisation, potential for coupling with hydrogen production and use, previous studies already carried out, and a political willingness.

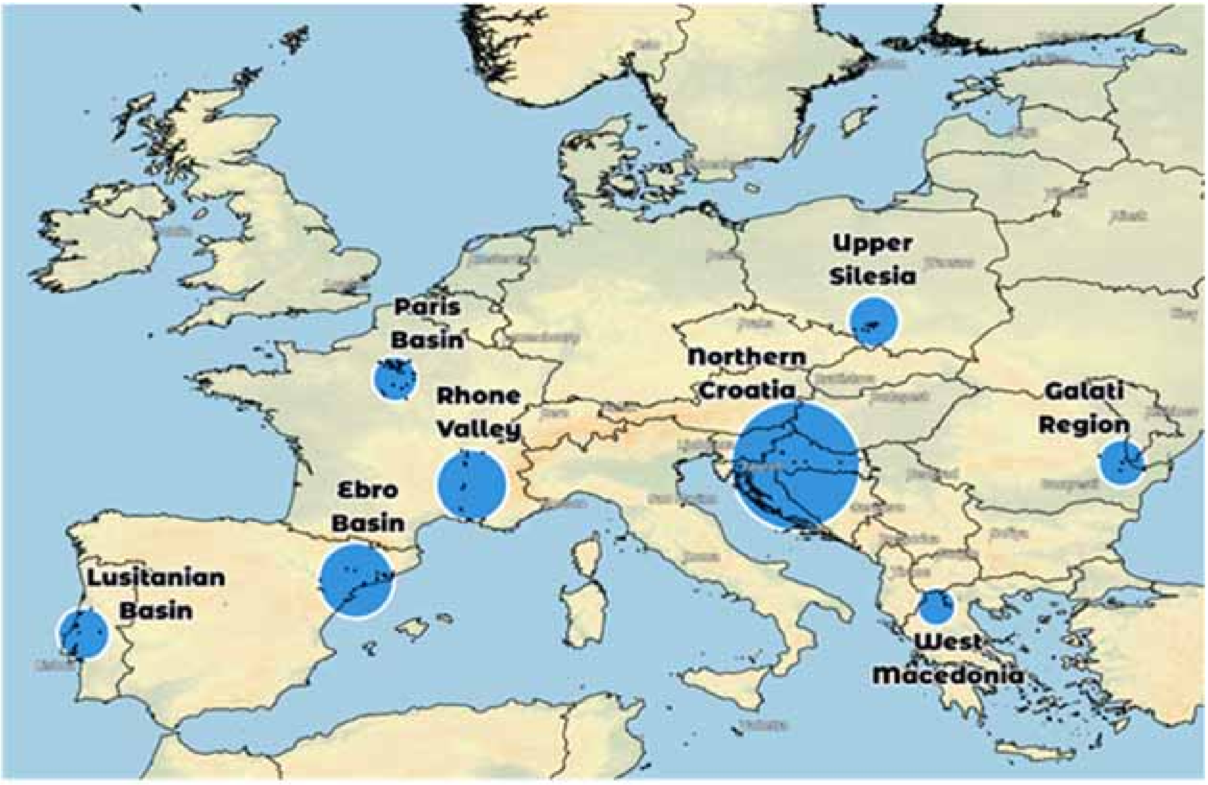

Figure 1-1: The eight promising regions studied in STRATEGY CCUS.

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Studied regions are listed below and illustrated in Figure 1-1:

- Paris basin in France (including Paris urban area, Ile de France and Loiret area)
- 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
- Ebro basin in Spain (including Tarragona industrial area, North Castellón and North Teruel areas)
- Lusitanian basin in Portugal (including the CO_2 sources in the Leiria -Figueira da Foz axis, and extending to Lisbon and Setubal)
- Northern Croatia (including Zagreb and the Croatian part of Pannonian basin)
- Galati area in Romania (including Galati, a port town on the Danube River, and its surroundings)
- West Macedonian area in Greece (including the Kozani and Ptolemaida industrial areas)
- Upper Silesia in Poland (including the industrial areas of Katowice, Rybnik and Będzin)

1.2 Objectives

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 and economically assess realistic strategic plans for CCUS development in Southern and Eastern Europe from 2025 to 2050. Specific objectives and outputs related to objectives are to:

• Develop local CCUS scenarios, related to realistic and local business models, within promising start-up regions;

The local CCUS scenarios are CCUS deployment plans and techno-economic assessments for the horizon 2025 and 2050 in each of the eight regions. These plans (*WP5- Establishing realistic detailed plans and techno economic evaluations for CCUS*) at different geographical and timescales were elaborated based on two main pillars, on one hand the European objectives of carbon neutrality in 2050 (including the share of CCUS) and their translation at national level and, on the other hand, infield data collected in each region by the STRATEGY CCUS project (*WP2- Mapping the technical potential of promising start-up regions*). These scenarios prepared in each country were presented and discussed at different meetings of the Regional Stakeholder Committees constituted in each region (*WP3 – Social acceptance: stakeholder mapping and engagement*) for being as realistic as possible.

Regional stakeholder committee meetings in each of the eight region (task 3.3) participated in the elaboration of regional CCUS scenarios with comments and insights related to local aspects (i.e.: considered industries for capture; public acceptance; transport routes; etc...). Members of stakeholder committee represented regional and national educated guess (D3.1 Stakeholder

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mapping report[3]) about CCUS technology (industries, researchers, politics and policies representatives, media, and NGOs) able to support project team in elaborating realistic scenarios (D3.2 Stakeholders' views on CCUS developments in the studied regions)[4].

The description of each scenario in terms of chosen industries to capture CO_2, its transport mode and connexions linking emission sources to geological storage and to utilisation sites is made in D5.2 - Report of the business case for each region[5]. Costs, economic evaluation, and Key Performance Indicators (KPIs) related to each scenario (business model) are detailed in D5.3 - Regional economic evaluation Report[6].

A common methodology of life cycle analyses (LCA), and Multi-Regional Input Output (MRIO) (D4.2[7]) and data templates (D4.1) are applied to CCUS technologies for the three most promising regions: Rhône Valley in France; Ebro basin in Spain and Lusitanian basin in Portugal. The whole life cycle analyses (LCA) of different CCUS processes were evaluated in D4.3[8] - LCA describes processes involved in CCUS, scaled to a common unit to understand and evaluate the various environmental impacts of the production processes. For these 3 regions, a socio-economic assessment through Multi-Regional Input Output (MRIO) analyses (D4.4[9]) examined the impact of CCUS deployment scenarios on the economy of the regions involved (e.g. gross domestic product (GDP) growth, job creation). LCA and MRIO (*WP4- Methodological developments for mapping environmental and economic drivers*), provide decision-support analyses 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.

Storage maturity of resources considered in most of regions is one of the main challenges with high uncertainty in building scenarios. Within the eight regions, storage resource estimates are low and classified as theoretical (exploration) and effective (prospective) resources. This low maturity increases the effective costs and the timing needed to put these resources in operation. A pre–Final Investment Decision phase concerning storage resources was assessed in D4.5[10] in terms of cost and feasibility related to the business model and incentives.

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[3] https://www.strategyccus.eu/sites/default/files/D3.1_STRATEGY%20CCUS_2019_08_28_StakeholderMappingReport.pdf
[4] https://www.strategyccus.eu/sites/default/files/D3.2_Stakeholders%E2%80%99%20views%20on%20CCUS%20developments%20in%20the%20studied%20regions_wDraftNote.pdf
[5] https://www.strategyccus.eu/sites/default/files/D5.2_CCUS_BusinessCases.pdf
[6] https://www.strategyccus.eu/sites/default/files/D5.3_V1_final.pdf
[7] This deliverable is confidential to project partners
[8] https://www.strategyccus.eu/sites/default/files/D4.3_LCA%20and%20TEA%20promising%20regions_20220408_FINAL.pdf
[9] https://www.strategyccus.eu/sites/default/files/D4.4_MRIO_Analysis_%20Final.pdf
[10] https://www.strategyccus.eu/sites/default/files/D4.5_Cost%20effectiveness%20storage_final.pdf

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The issues to facilitate the deployment of CCUS in each of the eight regions were evaluated for the three key pillars: techno-economic aspects; Social factors; and Policies and governmental factors in D5.6 [11].

• **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**.

Cooperative schemes were studied in Lusitanian basin area in Portugal (D5.5)[12] as well as the CO_2 prices thresholds required to ensure the business model and sharing of common infrastructure.

At European scale, the economic analysis of transnational scenarios (D5.4[13]) showed whether regional constraints can be relieved by, for example, capturing CO_2 in one region and storing it in another one, including more complex configurations where the captured CO_2 would be transported through several regions to a common storage site. The transnational scenarios considered are capturing CO_2 in Upper Silesia and sending it to storage to northern Croatia (scenario for Central Europe); and in another scenario, CO_2 captured in the Rhône valley is send to the Ebro region, CO_2 is then transport from the Rhône valley and the Ebro region to the western Macedonia region in Greece.

[11] https://www.strategyccus.eu/sites/default/files/D5_6_FullVersionFinal.pdf

[12] https://www.strategyccus.eu/sites/default/files/D5.5_Identification%20of%20sustainable%20cooperation%20schemes_final.pdf

[13] https://www.strategyccus.eu/sites/default/files/D5.4_Trans_final.pdf

2 Results of Project Work Packages

2.1 WP2 - Mapping technical potential of CCUS in the eight promising regions

Each of the promising regions, Paris basin and 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 required 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 utilisations for CO_2.

Local teams in each of the regions conducted assessments related to each of these technical features and implemented a methodology (D2.1)[14, 15] to produce a preliminary overview (D2.2 - sources, sinks, uses, corridors)[16] of the technical potential to develop CCUS clusters and networks in each promising region.

Mapping Industrial Clusters

Overall, 174 industrial and power facilities with CO_2 emissions in 2017 that amount to 121.5 Mt/y (Figure 2-1) were identified in the eight STRATEGY CCUS promising regions. Excluding power facilities, the CO_2 emissions amounted to 52.8 Mt/y (Figure 2-2), for the reference years 2017 and 2018, with iron & steel sector being the highest emitter. The Ebro basin, in Spain, seems to present the most complete set of conditions to deploy the technology, with a diversified industrial network, 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 the diversity of the industrial sources in the Rhône Valley is well-suited for defining a network of CO_2 capture and transport. In the same region a significant potential was identified CO_2 utilisation options in the chemical sector, for synthetic fuels and for mineral carbonation.

CO_2 utilisation is currently limited, but it can become an important path 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.

Other large-scale CO_2 uses are foreseen in connection to green hydrogen, namely in Portugal, where the roadmap 'National Hydrogen Strategy' relies in the ability to capture large volumes of CO_2 to

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[14] https://www.strategyccus.eu/sites/default/files/STRATEGY_CCUS_T2-1_ICCS_Methodology_V1.2.pdf
[15] https://www.strategyccus.eu/sites/default/files/STRATCCUSWP21-PART2-SRAM-v1.pdf
[16] https://www.strategyccus.eu/sites/default/files/STRATEGY_CCUS_D2_2_Data%20colection_WebsiteDRAFT-1_ReducedFileSize.pdf

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induce methanation and other chemical processes in order to produce synthetic methane / methanol 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 is 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 activity level of coal power plants. The technical context is certainly very good in terms of emissions' volumes and geographical distribution, and positive interactions with industry which is favourable for deploying CCUS clusters in the region. Storage conditions are, nonetheless, far from ideal, with a relatively small inventoried storage capacity.

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 both deep saline aquifers (DSA) and depleted hydrocarbon fields (DHF), able to provide safe conditions for storage while requiring less investments for increasing the maturity of the storage sites.

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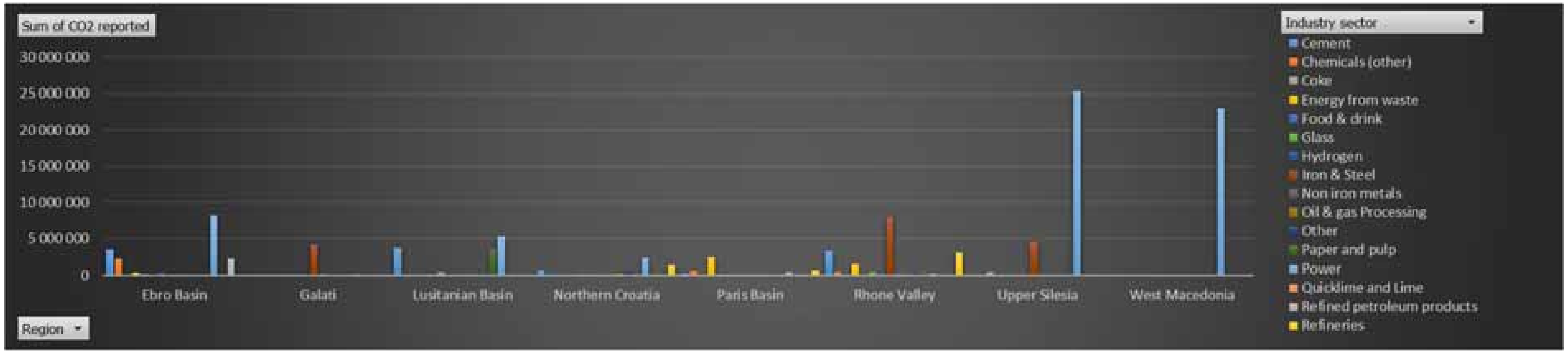

Figure 2-1: Quantity of CO_2 (tonne/year) reported in 2017 in each region for industry sector. (D2.4 - Databases filled for each promising region including ETS data – confidential).

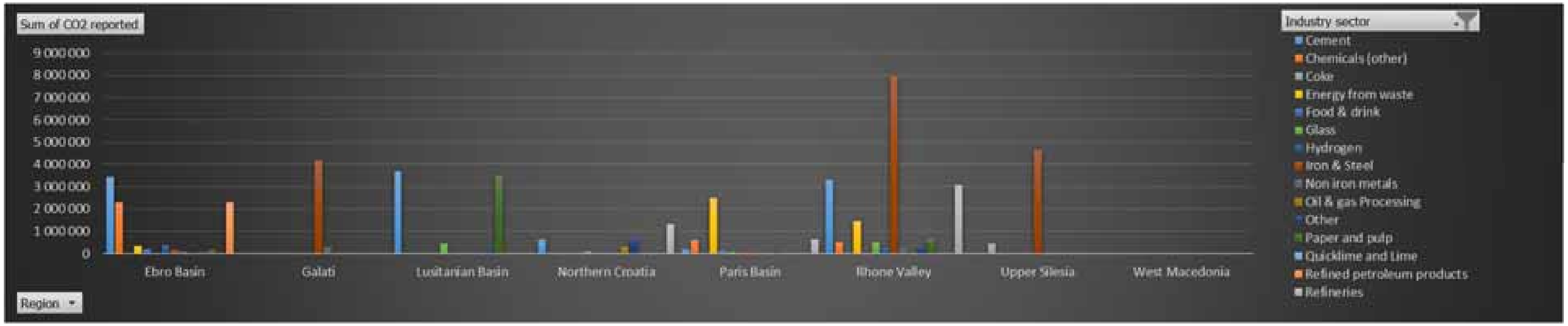

Figure 2-2: Quantity of CO_2 (tonne/year) reported in 2017 in each region for industry excluding power sector. (D2.4 - Databases filled for each promising region including ETS data – confidential).

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Mapping storage resources

In total, the storage resources of STRATEGY CCUS regions amount to 8.5 Gt CO_2 of capacity, where DSA represent ~ 92% of the type of resources and DHF around 8% (D2.3). A potential of 0.33 Gt of CO_2 could be used in North Croatia DHF and in Galati region (not counted). The storage capacities reported were calculated using, in most cases, a volumetric approach. In Paris basin and Upper Silesia, DSA 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 SEF 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.

Storage resources mapped in the eight regions are immature with low confidence. Using a quantitative and qualitative approach to describe storage capacity (D2.1b - Bridging the Gap, Storage Resource Assessment Methodologies), 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 2-3). 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 considering their confidence (uncertainty).

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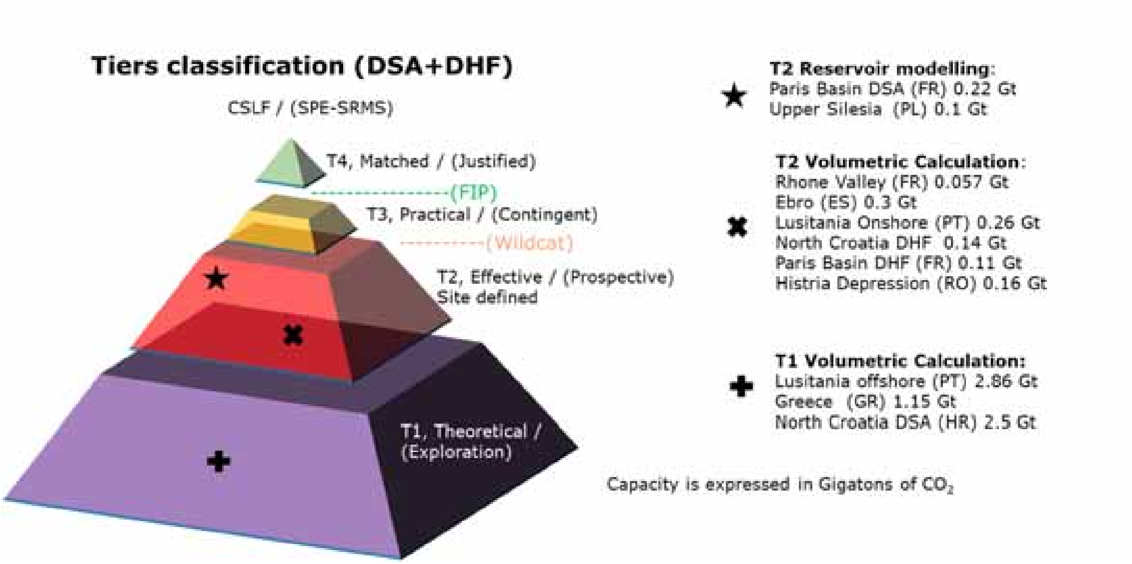

Figure 2-3: Pyramid classification of storage resources of the eight STRATEGY CCUS regions.

2.2 WP3 - Social Acceptance Stakeholders mapping and engagement

Since the diffusion of a technology is not only a technological but also a social challenge, the STRATEGY CCUS project had a dedicated Work Package 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 (D3.1)[17] and served as a basis to prepare further social acceptance studies.

To identify and map CCUS relevant stakeholders, 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 several 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. 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

[17] D3.1: Stakeholder mapping report.
https://www.strategyccus.eu/sites/default/files/D3.1_STRATEGY%20CCUS_2019_08_28_StakeholderMappingReport.pdf

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media. No earlier social acceptance research could be identified that focused specifically on the regions under study.

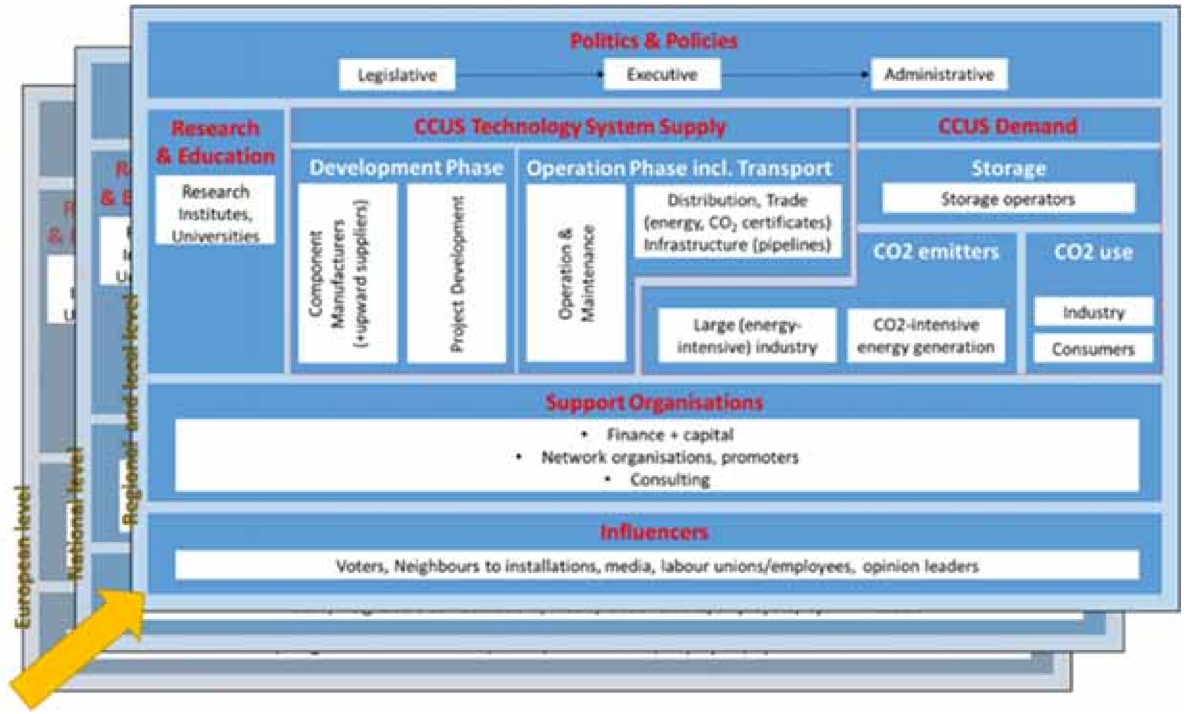

Figure 2-4: Actors in the CCUS technology system

Semi-structured interviews with selected members of the stakeholder groups were conducted in each of the regions to identify regional and national stakeholders concerned and playing role in the deployment of the CCUS technologies. The objectives of stakeholder' interviews were to evaluate: 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 as perceived barriers and enablers to the development of CCUS in their region; and preferences and expectations for energy futures (D3.2)[18].

A total of 102 interviews on the perception of CCUS were carried out (Table 2-1). 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).

[18] D3.2: Stakeholders' views on CCUS developments in the studied regions, report, pp 96. 2020 (https://www.strategyccus.eu/sites/default/files/D3.2_Stakeholders%E2%80%99%20views%20on%20CCUS%20developments%20in%20the%20studied%20regions_wDraftNote.pdf)

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Table 2-1: Types of regional stakeholder representatives that were interviewed in each promising region

Stakeholder type	France	France	Spain	Portugal	Croatia	Romania	Greece	Poland
	(Paris basin)	(Rhône valley)						
Politics and policies	5	2	2	-	3	2	5	2
Research and Education	3	-	5	3	2	2	5	4
Industry:	2	1	2	1	3	5	3	3
Demand side (adoption and use)								
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

Most of the stakeholders 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. In general 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.

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 sceptical about the introduction of CCUS 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

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petrochemical industries potentially interested in implementing CCUS technologies as well as to the onshore geological storage capacity.

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 (WP5). Each RSC consists of approximately 10-15 relevant and interested key stakeholders that were previously identified. Three workshops in national language were organized in each region with RSC members and project local team; two regions organized a fourth one, Paris basin region (France) and Ebro basin (Spain). Additional concerns and barriers on the CCUS implementation (that were not covered in the interviews) were collected from stakeholders. The first workshop focused on building a common ground and a first exchange for a long-lasting stakeholder network. The first presentation of scenarios being built in the WP5 was discussed during the second workshop. The last workshop was dedicated to present the final results of scenarios including the KPIs analysis. In the regions with a fourth workshop, it took place to enable a last discussion about scenarios before their publication.

Public survey in Spain and France

Representative surveys conducted within the general population in France - Rhône valley - and Spain - Ebro basin - (D3.3)[19] show that the level of acceptance of CCUS was about 50% (with higher levels of acceptance for CCU compared to CCS and slightly higher levels in Spain than in France). Interestingly, the levels of acceptance did not differ largely when comparing the results from the regional surveys (n = around 1300 each in Spain and France) with the national surveys (same approximate sample size as on the regional level). No clear NIMBY (i.e. Not In My BackYard) effects were observed. Taken together, although the knowledge and familiarity of CCUS in the general population was low (compared to the knowledge of stakeholders), general population in France and Spain showed a medium level of acceptance of CCUS.

Gaps and recommendations

A lack of public awareness of climate change and more precisely, a lack of awareness regarding the relevance of and the knowledge about CCUS is a major issue in public engagement towards CCUS technology. Relevant stakeholders' attitudes toward CCUS are in general positive, although the potential risk for the environment including the danger of leakage, the potential impact on existing natural and cultural heritage, as well as the potential lack of (local) public acceptance (e.g., due to a few loud voices and related emotions) are the main barriers today to deploy CCUS in studied regions. A good liaison between industry and further stakeholders as well as to attract new

[19] D3.3 Public acceptance of CCUS technology. A survey study in France and Spain. https://www.strategyccus.eu/sites/default/files/D3.3_STRATEGY%20CCUS_Dic_2021_SurveyReport.pdf

industries (including jobs) and to maintain existing jobs that fit to a high identification of the general public with the region and the related industry are perceived as enablers of CCUS deployment.

2.3 WP4 - Methodological developments for mapping environmental and economic drivers

The whole life cycle analysis (LCA) of different CCUS processes to understand and evaluate the various environmental impacts of the production processes was evaluated for the three most promising regions: Rhône valley in France; Ebro basin in Spain and Lusitanian basin in Portugal. For these 3 regions a Socio-Economic Assessments through MRIO analysis examined the impact of CCUS deployment scenarios on the economy of the regions involved (e.g. gross domestic product (GDP) growth, job creation).

A specific task evaluated effective costs to increase storage maturity to reach bankable status in each of the eight regions. The components of business models, i.e. revenue model (policy support mechanism), ownership structures, were discussed in the analysis of suitable business model for each region.

Life Cycle Assessment (LCA)

The CCUS scenarios developed in the frame of the STRATEGY CCUS project are meant to help decarbonize the economy by cutting direct CO_2 emissions and valorising or storing them. However, the net drop in GHG emissions linked to the implementation of these scenarios needs to be assessed in order to account for potential indirect environmental effects. Therefore, life cycle assessments (LCA) were performed to help in identifying the net benefits of CCUS and potential points of attention along the value chain, both in terms of GHG emissions and for other relevant environmental aspects. The whole LCA of different CCUS processes to understand and evaluate the various environmental impacts of the production processes was evaluated for the three most promising regions: Rhône valley in France; Ebro basin in Spain and Lusitanian basin in Portugal (D4.3)[20].

For each region, the set of relevant industrial emitters on which capture is planned is considered. Environmental impacts of the CCUS scenarios are compared to a baseline situation where no CCUS would be implemented, i.e. both direct CO_2 emissions would occur until 2050, and new products supplied through CO_2 utilization pathways would have to be supplied to the market in a conventional way (Figure 2-5).

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[20] D4.3 LCA in three selected promising regions describing processes involved in CCUS, scaled to a common unit. https://www.strategyccus.eu/sites/default/files/D4.3_LCA%20and%20TEA%20promising%20regions_20220408_FINAL.pdf

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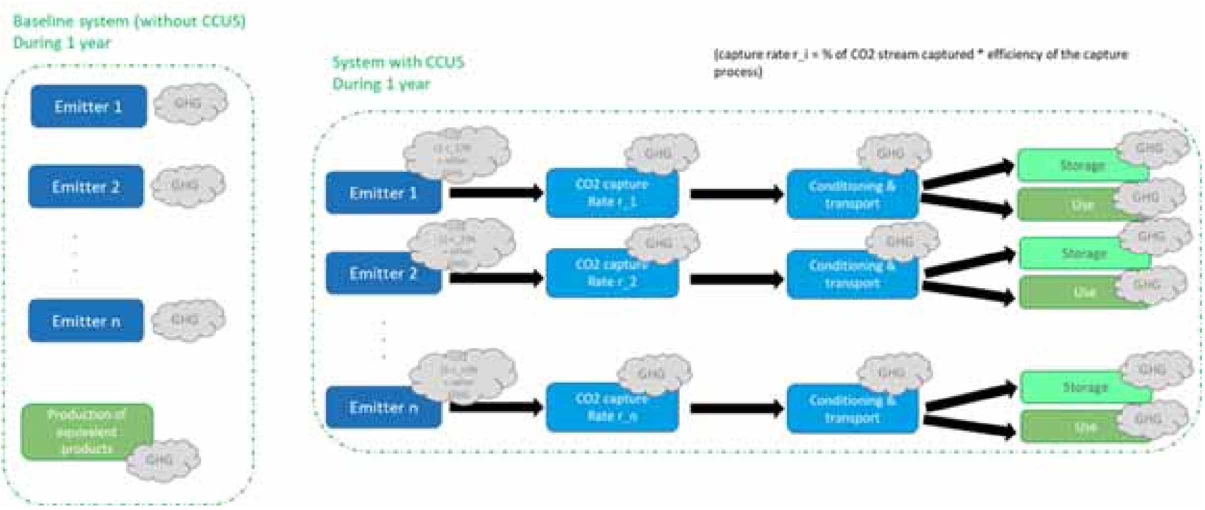

Figure 2-5: Schema of the baseline and CCUS system perimeters considered for the LCA

In the three regions assessed, the implementation of the CCUS enables net GHG and Cumulative Energy Demand (CED) savings compared to the baseline situation from 2020 to 2050. Capture process-related impacts (mainly because of energy provision, both through the upstream impacts of additional fuel supply and the related fuel combustion GHG emissions) are the most critical contributor to generated GHG emissions and significantly to CED, while the conditioning and transport chains globally bear insignificant contributions. The storage stage mainly involves a low electricity consumption for injection whose impact is negligible; moreover, the storage of biogenic CO_2 occurring in some regions implies negative emissions which are determinant in the global GHG balance as in the case of the Lusitanian basin, while negligible in the Rhône valley. Finally, the impacts of CO_2 utilisation strongly depend on the final use of CO_2 and on the transformation process settings (e.g. renewable power consumption for energy needs). However, the comparison of CCU impacts to those of the substituted conventional products supply and use (occurring in the baseline system) is mostly favourable to CCU, even though no prospective assumption on potential conventional process evolutions was taken.

In each case, the capture rate and energy consumption for capture, combined with the intensity of CO_2 emissions of the emitters, are found to be the ruling parameters of the GHG reduction efficiency of the CCUS scenarios. The base assumptions in each CCUS scenario (capture rate, energy for capture, conventional products substituted by utilisation pathways) play a key role regarding the LCA outcomes in terms of CCUS benefits. Therefore, process integration in the value chain is decisive to optimize net GHG emissions related to CCUS. However, CCUS definitely appears useful to succeed in cutting GHG emissions of the considered regions.

Multi-Regional Input-Output analysis (MRIO)

MRIO analysis concerns the socioeconomic benefits of CCS deployment in three selected promising regions: Ebro basin in Spain, Lusitanian basin in Portugal and Rhône valley in France. Departing from

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the scenarios elaborated in the WP5 and presented in section 3 of this document, the MRIO analysis concerns the value added and employment creation that would arise if the investments proposed do take place towards 2050.

The results point out (D4.4)[21] that more than 9,470 million euros (M.EUR henceforth, 2011 reference year) could be invested in CCS technologies during the period 2023-2050, contributing to capture almost 190 Mt of CO_2 in the in aggregate. Part of the invested amount would be creating value added and employment outside the European Union, due to global value chains: intermediates produced upstream such as extractive activities and different kind of services. However, around 89% of the total investment in the three regions would be retained inside our borders. Altogether, CCS would create 276,200 full time equivalent (FTE) jobs up to year 2050, both direct and indirect. That is approximately 11,050 permanent jobs. In Europe, the employment retained would be 203,300 FTE jobs (74%), or 8,130 permanent jobs (Figure 2-6). The rest is generated outside the European Union.

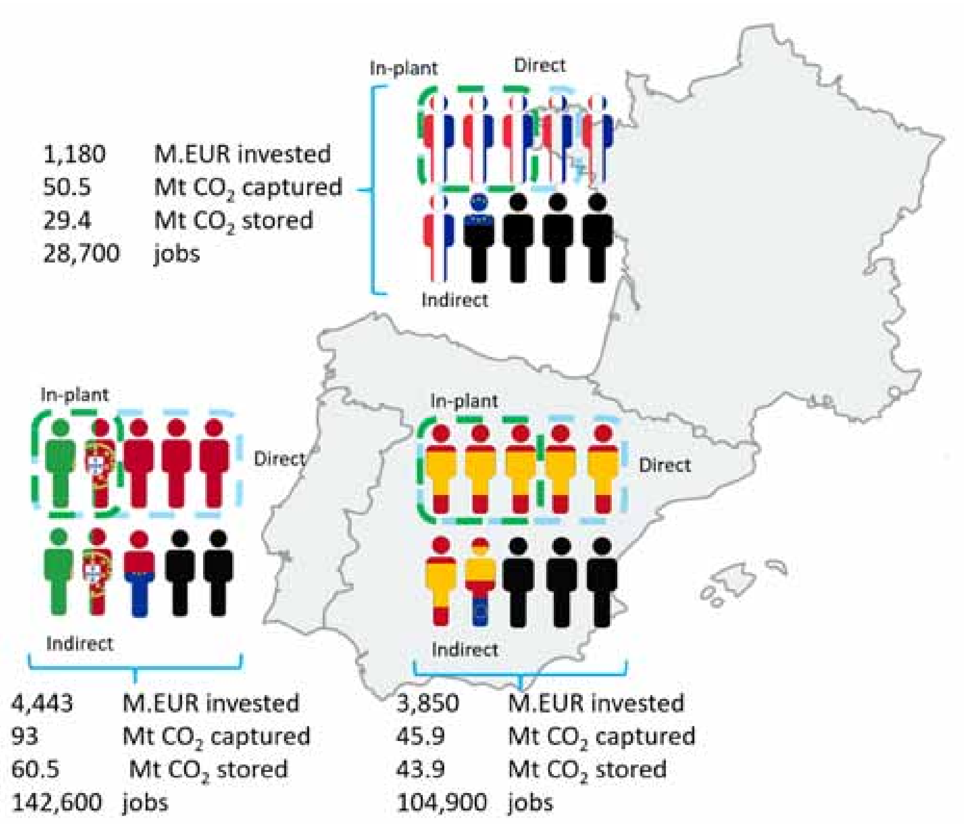

Figure 2-6: Results of MRIO analysis in Lusitanian basin (PT), Ebro basin (ES) and Rhône valley (FR)

[21] D4.4 MRIO analysis of CCS deployment of 3 selected promising regions. https://www.strategyccus.eu/sites/default/files/D4.4_MRIO_Analysis_%20Final.pdf

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Cost effectiveness of storage resources and Business model

Based on the outcome from WP2 (Mapping technical aspects), all storage sites in studied regions have not reached bankability status. The deployment time of increasing storage site maturity to bankability status may take between 5 to 10 years, depending on the current maturity and exploration loops. This finding suggests the necessity to carry out relevant work from today.

Costs to reach a bankability status in these eight regions were described as the pre-FID (Final Investment Decision) costs. Pre-FID costs estimated in STRATEGY CCUS regions represent between 1% (Galati region) to 6% (Rhône valley region) of total undiscounted storage costs calculated in WP5 (CAPEX[22] + OPEX[23]), which is less than the expected costs of 10% to 75% estimated by ZEP (2011).

The (undiscounted) costs of storage per tonne of CO_2 stored (CAPEX + OPEX) estimated in WP5 concern a site ready to be in operation and is a function of the quantity of CO_2 stored with low values for onshore option, as in Upper Silesia. These costs vary from 14 €/tonne of CO_2 stored (Lusitania basin onshore) to 60 €/tonne of CO_2 stored (Galati region).

Concerning the revenue models, today, most existing CCS projects receive policy supports. There are various supports (European levels or national levels), and in various forms (subsidy, specific contracts, etc). National funding possibilities exist as well, even they are not specific for CCUS. In the longer term, these supports are believed to evolve together with EU ETS system to ensure business profitability.

CCUS is a long value chain: it involves many sectors (power, cement, steel, chemical, , oil & gas, shipping, pipeline, etc) and hence various ownership models have been discussed (from vertically integrated to operator business models). It is recommended to segment CCS chain into 2 parts (CO_2 capture, and CO_2 transport/storage) or 3 parts (CO_2 capture, CO_2 transport, and CO_2 storage) in order to bring down market entrance barrier and allow more companies to participate in the market. Then for each part, Joint-Venture (JV) model is recommended in order to further share risks and accelerate development.

There is no business model applied for all regions, as it depends on local political mechanisms and market size. Based on the literature review in each region, it seems that vertically integrated CCUS business model cannot be applied in EU context as it requires a high investment and has a high associated risk. The best suitable business model considered in the studied regions would be risk shared ownership type, i.e. a JV model and/or a transport business model:

- CO_2 capture covered by CO_2 emitter or by a group of CO_2 emitters, and driven by development of a low-carbon product, and/or regulation on GHG emission at plant.

[22] Capital Investment costs
[23] Operational costs

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- CO_2 transport and storage can be covered jointly by the same company as service provider, or by two different companies with two service contracts. Business is driven as a service of transporting/storing CO_2 or capturing/storing CO_2.
- For CO_2 utilisation, it could be also driven by the market acceptance of CO_2 conversion products.

In this way, risk is shared along the value chain, and it allows more companies in the market and encourages cooperation among companies in different sectors.

Governments and private company alliances seem to be the key financial support providers.

2.4 WP5 - Establishing realistic detailed plans and techno economic evaluations for CCUS

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 cross-borders at transnational level. No connection to the North Sea CO_2 infrastructures was finally considered due to the high costs estimated. Whereas, connections between some regions were evaluated.

A dedicated tool was developed allowing to assess business case scenarios (D5.1)[24]. From a set of key data collected and the CAPEX/OPEX estimations of different technologies, possible CO_2 hubs and clusters were defined in each region. These key data include, but are not limited to: identified industrials emitters, quantities of CO_2 emitted, maximum existing 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 regional scenario, an economic evaluation was performed by local teams and discussed with the Regional Stakeholder Committees (WP3). 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 are provided by 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 CO_2 avoided or removed, etc.) was defined for all the scenarios. The economic analysis evaluated the cost for each scenario and for each industrial installation per ton of avoided CO_2. The transport corridors considered multiple time scales to identify the most cost-effective development of transport network, starting at the local level and/or pilot scale and evolving in the short to medium term to national and transnational levels in Rhône valley, Ebro Basin, Upper Silesia

[24] D5.1 Elaboration and implementation of data collected of the business case for each region (report and tool confidential to project partners)

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and North Croatia. The costs of transport were estimated based on the amount of CO_2 to be transported from each hub, and specification for each type of transport: pipelines (the generic design of pipelines, including the pipeline diameter, and number of boosting stations), ships, trains, or trucks, and OPEX. For the purposes of the analysis, a set of financial assumptions was adopted with relevant values regarding the discount rate; the uncertainty interval of costs; the costs of operations; materials; the energy and carbon prices.

Regional scenarios and economic evaluation[25]

CCUS scenarios studied in the eight STRATEGY CCUS regions (D5.2)[26] located in Ebro basin in Spain, Lusitanian basin in Portugal, Rhône valley and Paris basin in France, Northern Croatia, Galati area in Romania, West Macedonian area in Greece and Upper Silesia in Poland were elaborated based on two main pillars, on one hand the European objectives of carbon neutrality in 2050 (including the share of CCUS) and their translation at national level and, on the other hand, infield data collected in each region by the STRATEGY CCUS project (WP2-Mapping CCUS potential) i.e. the existing industrial emissions, existing CO_2 transport modes, known CO_2 storages, etc.

These scenarios, limited to 2050, are possible paths (among others) of how emission reduction targets can be achieved with CO_2 capture, use and storage in the different regions. None of the industry cited in this document has committed at this stage to implement the scenarios presented here.

Some scenarios presented in Region's Insights section are planning to start handling relatively small quantities of CO_2: 1 $MtCO_2$ per year in Paris basin and Lusitanian basin; 1.3 $MtCO_2$ in North Croatia; 1.5 $MtCO_2$ in West Macedonia basin; and 0.75 $MtCO_2$ in Ebro basin. Other scenarios are planning to handle bigger quantities of CO_2 like 9.35 $MtCO_2$ in Rhône valley or 10 $MtCO_2$ in Galati region. The Upper Silesia region is a medium size scenario starting handling 4.27 $MtCO_2$. Generally, the annual CO_2 emission considered in the different CCUS scenarios represent a small percentage of the national emissions: 0.3% in Paris basin, 1.5% in Upper Silesia, 2.3% in Lusitanian basin, 2.6% in West Macedonia, 3.2% in Rhône valley, 4.2% in Ebro basin. Only in two regions the quantity of CO_2 handled are around one tenth of the national emissions: 8.9% in Croatia, and 13% in Galati.

In France (Rhône valley) or in Upper Silesia, scenarios are highly constrained by the capability to store captured CO_2 as the storage sites identified and characterized are lacking. In contrast, some regions are limited by the availability of captured CO_2 and not by their storage capacity, like in Romania or Croatia, which opens the floor to intra-European scenarios.

[25] No industry has committed at this stage to implement the scenarios presented in the deliverable D5.2. The scenarios presented here, while based on an industrial reality on the ground, are forward-looking scenarios that explore the potential of CCUS in each of these regions

[26] D5.2 Description of CCUS business cases in Eight European regions. https://www.strategyccus.eu/sites/default/files/D5.2_CCUS_BusinessCases.pdf

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Galati and North of Croatia include CO_2 EOR to launch CCUS scenarios and to accelerate its deployment. These operations of CO_2 utilization are usually employed in hydrocarbon fields planned to be shut down as the reservoir will be become depleted. After the CO_2 EOR operation, CO_2 injection would be considered as permanently CO_2 storage in Depleted Hydrocarbon Fields.

Regions of Southern Europe have most of their emissions linked to industrial facilities other than power plant. In Portugal, the residual emission, i.e. those linked to the industrial process and difficult to reduce with current technologies, CCUS would be a good option for industries as the cement and lime factories. In Ebro basin, a large choice of industries with residual emissions from distinct sectors are considered, as well as in the Rhône valley. The Paris basin region has the specificity of attempting to implement CCUS close to an important town as Paris, to reduce their emissions that are almost linked to waste to energy plant (incinerators).

The deployment and technical-economic analysis of the eight CCUS scenarios in Southern and Eastern Europe have yield numerous lessons (D5.3)[27]. Among them:

- As a matter of course, the existing physical characteristics of each of the eight regions, i.e., the number and type of high CO_2 emitting industries, existing transport networks, as well as the estimated storage capacities or long-term CO_2 utilization in the region, greatly influence regional deployments of CCUS.
- Across the eight regions, nearly 78% of the CO_2 captured is ultimately avoided once the fossil-based CO_2 used in the production of fast-moving consumer goods (e.g. synthetic fuels) is released to the atmosphere. This ratio should be seen with great attention in terms of efficiency when deploying CCUS.
- Among the eight scenarios, Ebro basin is the most efficient one with 0.955 tons of CO_2 avoided per ton of CO_2 captured.
- Each scenario has its own efficiency in terms of euros per ton of avoided CO_2 and this efficiency is based on the different costs and different avoidance potentials of the elements of the CCUS chain.
- The amount of CO_2 avoided (357 Mt) in the eight regions is greater than the amount of CO_2 stored (343 Mt) due to the long-term use of CO_2 in mineralization (Western Macedonia and Ebro basin). This long-term use of CO_2 is of great environmental importance since it reduces the costs of CO_2 storage and increases the revenues of the CCUS chain. It should be promoted.
- In average, OPEX (up 2050) contribute 63% of total CCUS costs. These expenses should be reduced in priority to reduce the cost of the CCUS chain.
- Capture costs, for industries other than power plants, are high. This has a significant impact on the costs of the entire CCUS chain (capture costs generally represent a significant

[27] D5.3 Economic Evaluation of CCUS Scenarios in Eight Southern and Eastern European Regions. https://www.strategyccus.eu/sites/default/files/D5.3_V1_final.pdf

portion of total costs – 32% in average). Capture costs for CO_2 intensive industries other than power plants must be reduced in the future to limit the costs of the CCUS chain.

- When bioCO_2 is captured, it is essential to trace its use to certify whether it is a negative emission or not. Indeed, when captured bioCO_2 is stored in geological reservoirs or used in long-lived products such as mineralization, it may be considered a negative CO_2 emission. On the other hand, when the captured bioCO2 is used in short-lived products such as synthetic fuels, it may be considered as avoided (as substitutes the use of fossil fuels). Additional LCA-based analyses are needed to qualify net bioCO2 emissions (avoided or removed).
- The pooling of investment costs, particularly infrastructure costs, makes it possible to reduce the costs of the CCUS chain.

Considering the financial gap between CCUS costs and European Union Emissions Trading System (EU ETS), three long-term scenarios among those evaluated make CCUS more attractive (Figure 2-7): (1) Upper Silesia, which scenario is based on captured CO_2 on power plants and on 10 Mt CO_2 used for mineralization (4 302 M€ of lower costs with CCUS compared to EU ETS costs[28]), followed by (2) Paris basin including 9.1 Mt of negative emissions (1411.9 M€ but this case must be considered as a theoretical and exploratory one as it includes the incinerators in the EU ETS which IS NOT the case nowadays in France), and then (3) Northern Croatia with 1109.5 M€ of lower costs with CCUS compared to EU ETS costs.

On the other side, Ebro and Lusitanian basins present higher costs of CCUS compared to the estimated EU ETS compliance costs.

These results are however highly influenced by the EU-ETS scenario price.

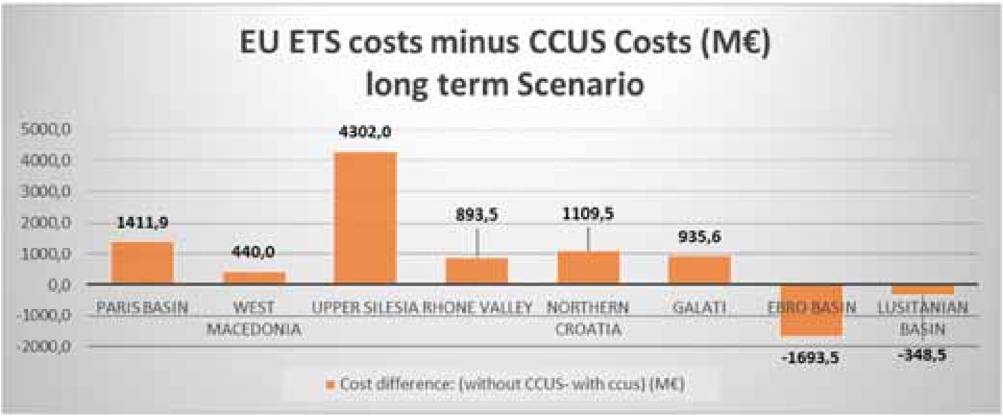

Figure 2-7: Financial gap between CCUS costs and EU ETS costs for a ETS price of 70€.

In the eight regions studied, common outcomes related to the economic analysis can be highlighted. The industrial sector and the public authorities should unify their strategies and roadmaps, to

[28] Based on the EUAs price scenario described in 2.2 General economic data

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develop private-public partnerships to jointly proceed to investments and reduce the CAPEX by optimising the infrastructures, which is particularly true for developing a pipeline transport network. Economic study of the scenarios would benefit from a sensitivity analysis of the various investment and operational parameters of the CCUS modules such as the efficiency of the various CO_2 capture technologies being considered, as well as the level of the storage resources (Tier 1 and Tier 2). As such, based on literature costs, an in deep and more detailed economic analyses should be conducted to reduce the economics uncertainties.

National and Transnational scenarios

A case studied in Portugal evaluated the least-cost infrastructure for connecting a geographically disaggregated set of emitting and storage clusters, as well as the CO_2 price thresholds required to ensure a business case for investment decisions (D5.5)[29]. A modelling approach assessed the relevance of various policy scenarios, including (i) the perimeter of the targeted emitters for CCS uptake and (ii) the relevance of constructing several regional networks instead of a single grid to account for the spatial characteristics of the Portuguese region.

One single network naturally emerges in the centre of Portugal. The presence of separability in the system implies the possibility of separating two subsystems that share the same storage site. Because these subsystems may be deployed independently, governments do not need to focus their efforts on building a large-scale national infrastructure; instead, a regional approach to CCS implementation is preferable. Cost-engineering analyses based on average cost assumptions may understate the exact break-even price. The high capture costs of certain emitters have a direct impact on determining the price for CCS infrastructure adoption. These clusters with large CO_2 costs relative to their low annual CO_2 emissions are the least attractive candidates to be included in the potential coalition for CCUS adoption. The policy implications of these findings concern the elaboration of relevant, pragmatic recommendations to envisage CCS deployment locally, focusing on emitters with lower CO_2 capture cost options.

Looking at transnational scale, three scenarios with a variant were evaluated based on the regional scenarios. Regions that exhibit limited storage capacities qualified by their storage filling rate by 2050 were identified, as well as regions characterized by high-capacity storage facilities and that still have significant available capacities in 2050. Based on geographical arguments, pairs or trios of regions that could form clusters so as to avoiding transporting CO_2 over too long distances were identified.

The first scenario transports the CO_2 captured in Upper Silesia to northern Croatia (scenario for Central Europe). In the second scenario, the CO_2 captured in the Rhône valley is transported to the Ebro region, and a variant of this scenario, the third scenario, by transporting the CO_2 from the

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[29] D5.5 Identification of sustainable cooperation schemes in Portugal: Break-even CO_2 prices for CCS adoption. https://www.strategyccus.eu/sites/default/files/D5.5_Identification%20of%20sustainable%20cooperation%20schemes_final.pdf

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Rhône valley and the Ebro region to the western Macedonia. Interestingly, transnational scenarios give more flexibility to the CCUS chain by avoiding storage capacity constraints in highly industrialized regions. By lifting the limitation on the storage capacity, it is even possible to increase the quantities of CO_2 captured by:

- Twice for the Upper Silesia / Northern Croatia scenario
- +27% for the Rhone Valley / Ebro / Western Macedonia scenario

With these three transnational scenarios, the total quantities of CO_2 captured in these 4 regions exceed 400 Mt, i.e., more than for the 8 initial regions. From the point of view of the physical quantities of CO_2 captured and transported, the transnational scenarios are of real interest for the planet, the economic analysis of the transnational scenarios does not make it possible to highlight the effects of scale on the cost of the ton of CO_2 avoided. The costs obtained are comparable to those resulting from the regional analyses and remain relatively low. Unsurprisingly, transnational scenarios increase transport costs, especially when using ships.

Analysis of the impact of the scenarios on the EU ETS

The deployment of CCUS may have an impact on the European Union Emissions Trading System (EU ETS), as no European Union Allowances (EUAs) is required for any CO_2 captured and not emitted to the atmosphere.

The deliverable D5.7[30] assessed the CCUS impact on the EU ETS by evaluating the quantity of allowances not required with CCUS scenarios developed under the project on the regional and European scales. The analysis is performed by evaluating the quantities of CO_2 avoided through CCUS implementation throughout the scenarios with quantities of EU ETS allowances (EUA) theoretically issued. The projected quantities of allowances are determined by applying linear reduction factors of 2.2 % and 4.2 % to those allocated in 2021.

The STRATEGY CCUS scenarios allow industrials in the 7 countries studied to avoid purchasing a significant volume of allowances equal to 10% in 2040 (and 1.7% in 2030) of the total EU stationary installations allowances using a linear factor of 4.2%. At national scale, CCUS may have a stronger impact on the EUAs demand since it allows reducing sometimes significantly industrial CO_2 emissions.

In terms of CO_2 price, the impact of CCUS on the EU ETS is a reduction of the EUAs demand so mechanically a reduction of the CO_2 price. All else being equal, a 10 % reduction in EUAs demand will be very sensitive to a reduction CO_2 price as the EU ETS is a very responsive market. That means for the long term, if CCUS projects will be largely deployed, the Market Stability Reserve need to be very efficient and react quickly to the excess of EUAs.

[30] D5.7 Impact of CCUS Scenarios on the EU ETS. https://www.strategyccus.eu/sites/default/files/D5.7_ETScenariosImpact_clean.pdf

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

2.5 WP6 - Strategic communication and dissemination for CCUS development

STRATEGY CCUS is a Coordination and Support Action project, in which communication and dissemination activities played a central role in achieving the objectives. The project's ambition to learn from past and current CCS projects was supported by webinars, online meetings and workshops. All project's further developments and the evaluation of integrated CCUS development scenarios were supported by the project communication tools (website, stakeholder toolbox, and the project SharePoint where documents were exchanged between partners). This work package supported effective communication between partners involved in the project and ensured all public deliverables were effectively shared with external stakeholders, such as local public authorities and citizens at regional and European level using a range of communication channels (regional events, conferences, publications, website, social media, and videos).

Impact of project website

An essential communication tool, supporting communication between projects partners and promoting CCUS activities to stakeholders in Europe, the website was designed to present the project, the partners and the promising startup regions.
The website itself was made public on the 30th of July 2019. The web address is as follow: http://www.strategyccus.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Home page

The STRATEGY-CCUS home page opens with a carousel of images linking to most recent news and events, followed by a short paragraph describing the project and including links to the different work packages. Following these, the home page features a collection of easy-to-access links to other sections of the website, presented in a visual form. The logo and branding are visible throughout, making use of the pre-established colour palette and fonts. The main menu remains anchored to the top of the page, even as the user scrolls down, to allow for quick access to other sections. The footer features a site map, links to social media accounts (Twitter, LinkedIn, and YouTube), and the official funding acknowledgement and EU emblem.

About the project

The "About the Project" page sets out the project mission & vision, includes the duration of the project, and provides details about the transnational nature of the project, as well as drawing attention to the 8 promising regions. It includes a link to download the project briefing (PDF), links to relevant subpages (described below), and a description of the importance of CCUS in Europe. This page has related subpages to present further information about the STRATEGY-CCUS project:

Project Objectives and Work package synergies: The *Project Objectives* page presents the project aims, goals, and long-term goals, and provides links to each one of the 6 work packages. Whilst the *Work package synergies* page describes the interaction between work packages and their associated partner institutes.

Partners, Advisory Board, and Industry Club: These pages present images, descriptions and external links for the 17 project partners from 10 countries, as well as members of the Advisory Board and Industry Club.

Regions: This page summarises the 8 promising regions and has a downloadable map infographic. It also presents a map with links to further pages with detailed information about each region, including the option to download the project briefing (PDF) in each of the regional languages: Portuguese, Spanish, French, Croatian, Rumanian, Greek, and Polish.

Funding: The STRATEGY CCUS project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 837754. This page provides additional information about Horizon2020 and provides a link to the European Commission's website.

Useful Links: This page provides a long list of relevant links in the following categories: CCUS initiatives, CCUS Projects (including EU-sponsored), and Climate Change.

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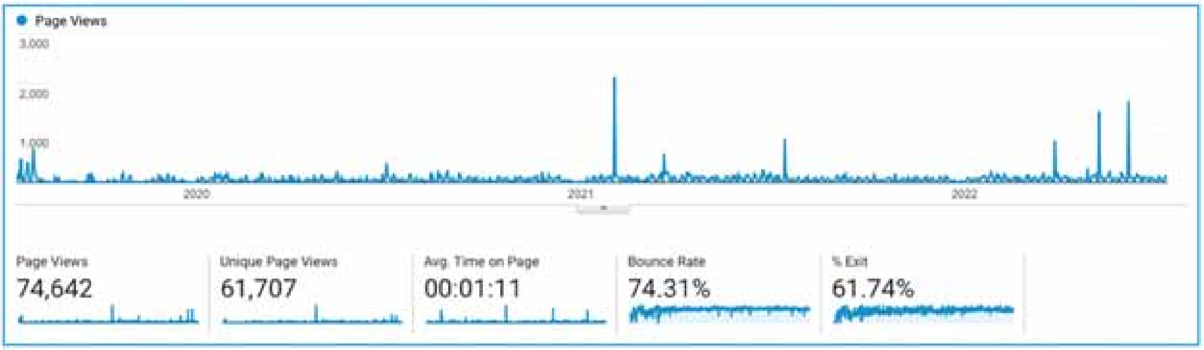
Website analytics

The project started tracking website analytics on the 14 July 2019, using Google Analytics. The following is a summary of key analytics indicators for a 3-year period, up to 13 July 2022. Over the course of the project, the STRATEGY-CCUS website had a total of 74,642 page views. This represents a yearly average of 24.8K page views and a monthly average of 2K page views.



Toolbox

The Stakeholder Engagement Toolbox was prepared to provide a set of resources that can be used by project partners and potential CCUS developers, to run themed events and meetings relevant to local stakeholders and their needs. The toolbox was assessed and reviewed during the project, and the final version is now on the website. It includes: a collaborative video introducing each of the 8 regions and highlighting the importance of CCUS, project briefings (PDF) translated in different languages, project infographic (PDF), a guide to running successful webinars (PDF), and a guide to media and social media engagement (PDF).
In addition, stakeholders will have access to a collection of researcher's blog, webinar recordings, Newsletters and project report, all can be used to prepare CCUS related events.

Project outputs

The project's key findings and outputs are available in this section, under one of the six headings: Methods (WP1), Economics (WP4), Stakeholder engagement (WP3), Web maps (WP5), Communication (WP6) and Project management outputs (W1).

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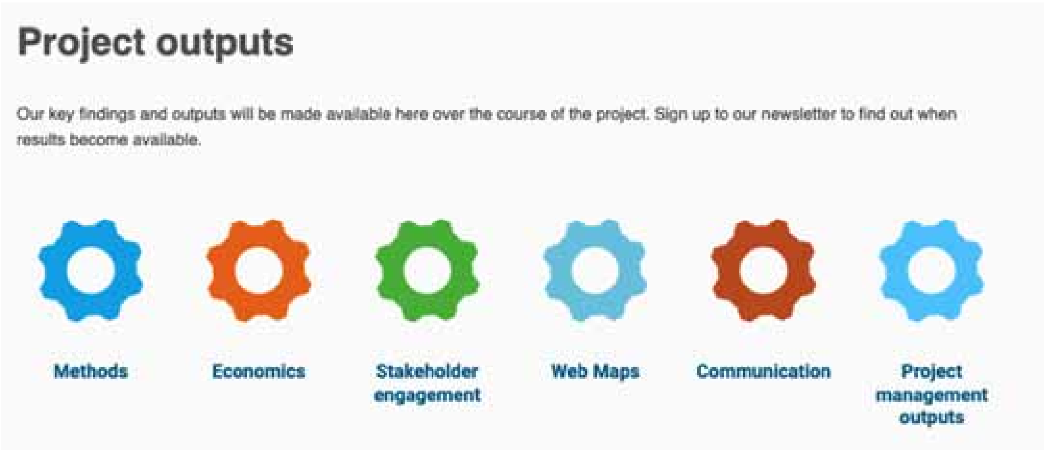
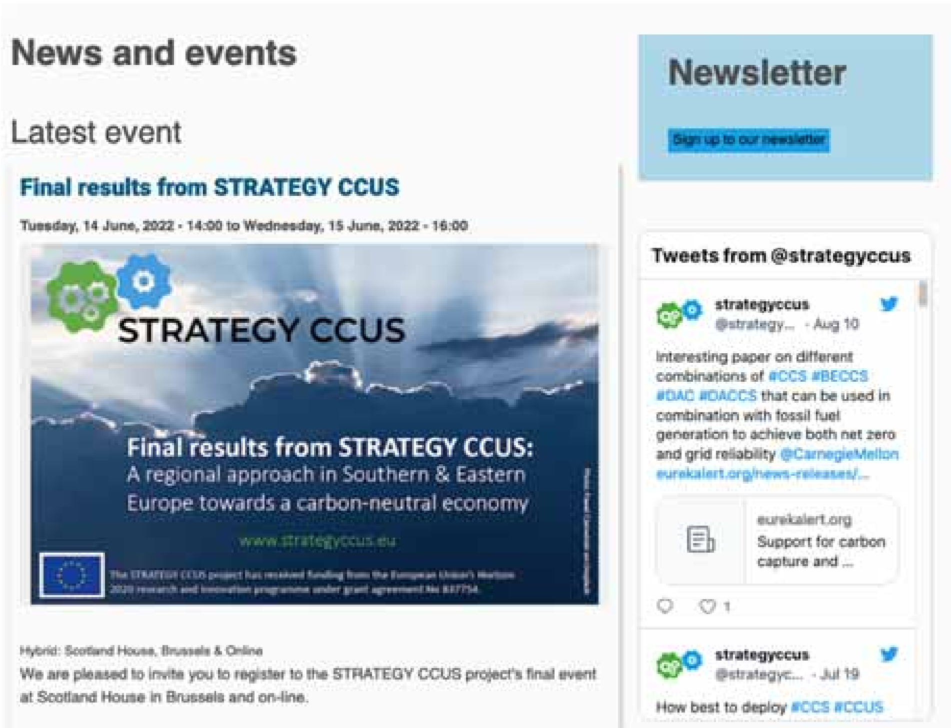


Newsletters

The project published five newsletters, the first one in December 2019, the second in September 2020, the third in March 2021, the fourth in September 2021 and the fifth one in May 2022.

- 35 News articles published
- 16 Events shared, including webinars, and other events involving project partners
- Newsletters' analytics: nearly 75K page views over 3 years of the project. This represents an average of 2K page views per month.



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Regional events

The regional events were designed as half-day or one-day conferences and organised by the regional teams involved in the project. The main objectives of these regional events were (1) to disseminate the project's outputs, (2) to raise the awareness level on CCUS options at regional and national level, and (3) to increase the engagement level and develop the network of regional stakeholders already formed through Regional Stakeholder Committee Workshops.

A total of seven regional events were organised between March and May 2022, of which one was organised as a face-to-face meeting (in Greece), two were online (in Romania and Portugal), and four were hybrid (in Spain, France, Poland, Croatia). Also, six events out of seven were half-day conferences, and only one (the regional event in France) covered a full day. Further, six of the seven regional events were organised in the national language, while only the regional event in Romania was organized in English language.

Although the agenda of the event was specific in each region according to the perspective of the organizing team, all the regional events had in common the presentation of results for the region involved and at least one interactive session with the participants. The level of attendance ranged from 40 participants (in Croatia) to 100 (in France). The events attracted mostly Industry representatives, the Industry being the most prominent and active category of attendees, and also researchers interested in CCUS development.

Events were mostly publicised on social media, but also on mainstream media. Online events had the possibility to livestream which helped increase their audience level.

All regional events were evaluated at two levels: 1) from the perspective of the project team (evaluating the effectiveness of organisation, conditions, the audience, level of dissemination), and 2) from the participants' perspective using evaluation questionnaires via Google forms and by collecting direct feedback. On the first level of evaluation (from the perspective of organisation) the regional teams considered that their objectives of dissemination of project results in the region were accomplished) On the second level, from the perspective of publics, all the events were considered by the participants as being instructive, relevant in content and offering an adequate frame and time for interaction.

Final event

The project's final event was organised in Brussels on the 14th and 15th of June 2022 as a hybrid event. All partners and work package leaders were present over this two-day event to which over 200 persons attended.

DAY 1 - Tuesday June 14, 2022, from 2pm

V 13/06/2022

STRATEGY CCUS

FINAL EVENT

June 14-15, 2022 • Scotland House,Brussels

Agenda

STRATEGY CCUS

Day 1: Tuesday June 14, 2022						Connection link Session 1 https://urlz.fr/ivda
Agenda item	START	Length	END	CONTENT	MODERATION	COMMENTS
1	13:30	30	14:00	**Welcome Coffee and registration**		The venue will be opened to participants from 13.00
2	14:00	5	14:05	**Opening Session**	I.Czernichowski (BRGM)	
3	14:05	20	14:25	**Key-note Speaker Introduction**	F. de Mesquita Veloso (BRGM)	*Vassilios Kougionas - Policy Officer for CCUS EC -DG RTD (TBC)*
Session 1 - PRESENTATION OF SCENARIOS RESULTS /REGION FOCUS						
4	14:25	15	14:40	**Overview of the 8 CCUS regional scenarios :** Starting from an European map with the 8 localizations of the scenarios => 8 zooms in the 8 regions	R. Berenblyum (NORCE)	
5	14:40	20	15:00	**Economics of the scenarios :** "comparison" of the 8 regions	P. Coussy (IFPEN)	
6	15:00	15	15:15	**Q&A session** *on Economics of Scenarios*		
7	15:15	20	15:35	**Transnational CCUS approach** Presentation of 4 scenarios	X.Guichet (IFPEN)	
8	15:35	15	15:50	**Q&A session** *on Transnational CCUS approach*		
9	15:50	30	16:20	COFFEE BREAK		
10	16:20	20	16:40	**Sustainability assessment of CCUS in the 3 main regions:** LCA and MRIO results	Y. Lechon (CIEMAT) (online)	
11	16:40	15	16:55	**Q&A session** *LCA & MRIO on the 3 main regions*		
12	16:55	20	17:15	**Social acceptance of CCUS**	S.Preuß (Fraunhofer ISI)	
13	17:15	10	17:25	**Q&A session** *on Social acceptance*		
14	17:25	20	17:45	**Storage maturity and actions towards bankability**	F. de Mesquita Veloso (BRGM)	
15	17:45	10	17:55	**Q&A session** *The specificity of storage maturity*		
16	17:55	15	18:10	**Conclusions**	F. Delprat-Jannaud (IFPEN)	
16	17:55	120	19:55	ICE BREAKER		The ice breaker will take place at the venue, until 20.00/20,30, open to all participants

The meeting started at 2 pm after a welcome coffee.

Dr Isabelle Czernichowski welcomed the participants and opened the meeting. She provided information about the project, recalling the context of Covid-19 pandemics. Despite the impossibility to meet in person, the team faced and adjusted to the situation in order to achieve the goals set in the Grant Agreement, including virtual meetings with regional stakeholders.

Dr Vassilios Kougionas, European Commission policy officer for CCUS, at DG Research and Innovation in the Clean Energy Transition Unit, shared the goals, policy tools and expected impacts regarding CCS and CCUS towards clean Energy transition in Europe. He followed with a review of Horizon Europe programme and next steps to reach CCUS2030 targets, outstanding projects and Carbon Dioxide Removal (CDR) missions.

The STRATEGY CCUS regional teams and partners then took over to present scenario results from a regional point of view, focusing on economics, trans-regional CCUS approach, Life Cycle Assessment (LCA) and Multi Regional Inputs and Outputs (MRIO). The importance of Social acceptance of CCUS

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and the studies and interviews carried out with stakeholders at local, regional and national level were also stressed. Finally, project coordinator Fernanda de Mesquita L Veloso wrapped up the review of project results exposing the challenges raised by storage maturity and the way to bankability in the various regions, pointing out main findings and prerequisite steps.

Florence Delprat-Jannaud from IFPEN concluded the afternoon session with references to the IPCC report for Policy makers, pointing to the need for CCUS deployment, and the current situation of CCS and CCUS deployment projects mainly in Northern and Western Europe. She emphasised how the progress and achievements of STRATEGY CCUS, with their specific regional point of view, were opening new perspectives and European synergies for further deployment of CCUS in Europe, including a sequel project PilotSTRATEGY. She finally invited participants to register and join the next GHGT 16 conference in Lyon (France) on Oct 23-27, 2022[31].

DAY 2 - Wednesday June 15, 2022, from 9 am to 4.30pm

Day 2 of STRATEGY CCUS Final Event was dedicated to presentations, roundtables and discussions on crucial steps for CCUS delivery in Europe in the morning, followed in the afternoon by talks and discussions on the way forward, progressing from results to actions. The panel of participants and speakers was composed of policy and decision makers at national and European level, stakeholders and Advisory Board and Industry Club members.

[31] https://ghgt.info/

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Morning Session – 9 am to 12.15pm

Day 2: Wednesday June 15, 2022						**Connection link Session 2 (am)** https://urlz.fr/ivdl
Session 2 - Morning - ROUND TABLE: CRUCIAL STEPS FOR CCUS DELIVERY, WITH POLICY MAKERS AND STAKEHOLDERS AND ADVISORY BOARD MEMBERS						
Agenda Item	START	Length	END	CONTENT	MODERATION	COMMENTS
1	8:30	30	9:00	**Welcome Coffee and registration**		The venue will be opened to participants from 8.30
2	9:00	5	9:05	**Introduction from one project partne**	F.de Mesquita Veloso (BRGM)	
3	9:05	30	9:35	**Industry clusters** How UK and Norway tackled these challenges, what they did and how they overcame them Testimony from other projects	Ch. Gorecki (UNDEERC)	to introduce the session and chair
	9:35	30	10:05	**Roundtable > Key Questions**		
4	10:05	30	10:35	COFFEE BREAK		
5	10:35	15	10:50	**CCUS in sectors – Introduction from one project partne**	F.de Mesquita Veloso (BRGM)	
	10:50	60	11:50	**6 Sector presentations (10min per sector)** • EOR (Dubravko Novosel, INA d.d.) • Cement (Maxime Butler, Lafarge Holcim) • Coal (Corwyn Bruce, Sask Power and Lehigh Hanson) • Steel (Damien Chambolle, Arcelor Mittal) • Refinery (Ivan Rodriguez, Concawe) • Waste to Energy (Martus Tednes, Fortum Oslo Varme)	Romain Viguier (UEDIN/SCCS)	
6	11:50	25	12:15	ROUNDTABLE: eliciting and gathering opinions, concerns and advice of roundtable participants (online & in-person – enable input from All)	Romain Viguier (UEDIN/SCCS)	
7	12:15	60	13:15	LIGHT LUNCH		The lunch will take place at the venue, open to all participants

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Afternoon Session – 13.30 to 16.30

Session 3 - Afternoon - DISCUSSION: WAY FORWARD: TALKS and DISCUSSIONS " FROM RESULTS TO ACTION"

Day 2: Wednesday June 15, 2022						Connection link Session 3 (pm) https://urlz.fr/ivdw
Session 3 - Afternoon - DISCUSSION: WAY FORWARD : TALKS and DISCUSSIONS " FROM RESULTS TO ACTION"						
Agenda item	**START**	**Length**	**END**	**CONTENT**	**MODERATION**	**COMMENTS**
1	13:30	5	13:35	**Welcome note**	P.Rocha (CIMPOR)	
2	13:35	15	13:50	**Setting the scene I A vision from three different angles**	Paulo Rocha (CIMPOR / Innovation & Sustainability	
3	13:50	40	14:30	**The major techno-economical roadblocks and how to overcome them - Roundtable** Structured Session (Q&A with final notes)	F.de Mesquita Veloso (BRGM)	I Volker Hoenig (ECRA / Managing Director) (OK / online) I Nicolas Peugniez (GRTgaz / Deputy Strategy & Regulation Director) (OK / in person) I Xxxx Xxxx (CEFIC in Brussels) (tbc / online) I Per-Olof Granström (Zero Emissions Platform / EU Director) (OK / in person)
4	14:30	10	14:40	BREAK		
5	14:40	30	15:10	**The central role of social dialogue in CCUS deployment** Structured Session based on Mentimeter questions (Q&A + Mentimeter) Remarks from moderator and invited person on Q&A of Mentimeter:	Sabine Preuß (Fraunhofer ISI) + Diana Cismaru (Communicare Ro)	
6	15:10	40	15:50	**Moving ahead and required supporting policies** Structured Session (Q&A with final notes)	Jonas Helseth (Bellona / Director Bellona Europa aisbl)	I Carlos Zorrinho (MEP S&D PT / ITRE Committee) (OK / online) I Maria da Graça Carvalho (MEP EPP PT / ENVI Committee) (OK / online) I Pedro Mora (PTECO2-Spanish CO2 Technology Platform / Vice-President) (OK / in person) I Volker Sick (Director 'Global CO2 Initiative') (OK / online)
7	15:50	10	16:00	**Wrap-up & Thanks**	F.de Mesquita Veloso (BRGM)	
8	16:00	10	16:10	**Closure**	I.Czernichowski (BRGM)	

The afternoon session was dedicated to talks and discussions on how to move ahead to deploy CCUS further, which requirements, policies, regulatory framework, etc… and how to step from results to action.

After recalling STRATEGY CCUS project main features and results, Paulo Rocha (CIMPOR) provided an overview of the global situation, introducing a vision from 3 different angles: techno-economics, societal and policy recommendations (Political / Regulatory & Legal). He then left the floor to the 1st Round table on the major techno-economical roadblocks and how to overcome them. Moderated by Fernanda Veloso (BRGM / Project coordinator). Members of the panel:

- Volker Hoenig (ECRA / Managing Director) (online)
- Nicolas Peugniez (GRTgaz/ Deputy Strategy & Regulation Director) (in person)
- Carla Pedro (APQuímica -Managing Director) (online)
- Per-Olof Granström (Zero Emissions Platform / EU Director) (in person)

Then followed the second panel with an open discussion on "The central role of social dialogue in CCUS deployment", led by Sabine Preuß (Fraunhofer ISI) who set up the context then used Mentimeter sessions to interact with the attendees (online and in person).

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The last roundtable, chaired by Jonas Helseth (Bellona/ Director Bellona Europa aisbl), welcomed the participation in person of two EC Members of Parliament, Maria da Graça Carvalho (MEP EPP PT / ENVI Committee) and Carlos Zorrinho (MEP S&D PT / ITRE Committee) and Pedro Mora (PTECO2-Spanish CO2 Technology Platform / Vice-President). Volker Sick (Director 'Global CO2 Initiative') participated online. The discussion subject focused on how to move ahead, and planning/setting up the required supporting policies.

Isabelle Czernichowski and Fernanda de Mesquita L. Veloso (BRGM) wrapped-up and delivered the conclusions of the event.

The presentations[32], discussions[33] and posters [34]shared during this final event can be found on the project website.

Being a Coordination and Support Action project, STRATEGY CCUS had strong communication and dissemination objectives. They were fulfilled with a wide range of activities throughout, in support of research led by the Consortium and successive results, and to share them with external stakeholders at all levels from local to European, and from all sectors. Public project deliverables, webinars, newsletters, tools (webmaps, stakeholder toolbox, posters, etc…) are now available on the project website for future use.

STRATEGY CCUS focused on the feasibility of CCUS technology in eight territories in Europe elaborating local scenarios with the support of stakeholders, thus creating a regional dynamic. It paved the way to another project, PilotSTRATEGY which with various former project beneficiaries and in line with these outputs will continue to investigate and increase the maturity of storage resources, five Deep Saline Aquifers already identified as potential geological storage sites, in five STRATEGY CCUS regions and enlarge the panel of stakeholders.

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32 https://www.strategyccus.eu/sites/default/files/Final%20Event_Presentations_Attendees_list.pdf
33 https://strategyccus.eu/project-outputs/stakeholder-engagement-outputs
34 https://strategyccus.eu/toolbox

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3 Region's Insights

This section gives an overview of main insights of each STRATEGY CCUS regions.

Starting from the geographic location of regions, infographics illustrate main scenarios studied and evaluated by economic modelling. These figures showed installations considered for capture, proposed transport networks to storage sites and/or utilization facilities.

The KPIs set is presented. Costs are discounted and annualized all along the scenario's trajectories and follow common economic values (Table 3-1).

Table 3-1 Common economic data and regional sites specific data

Common economic data	Value	unit
Price reference year	2021	year
Discount rate	5	%
Inflation rate	2,5	%/year
Learning cost factor for capture	-1	% /year
EUAs on EU-ETS price (yearly average): MEDIUM scenario In 2021 In 2050	 70 212	 €/t CO2 €/tCO_2

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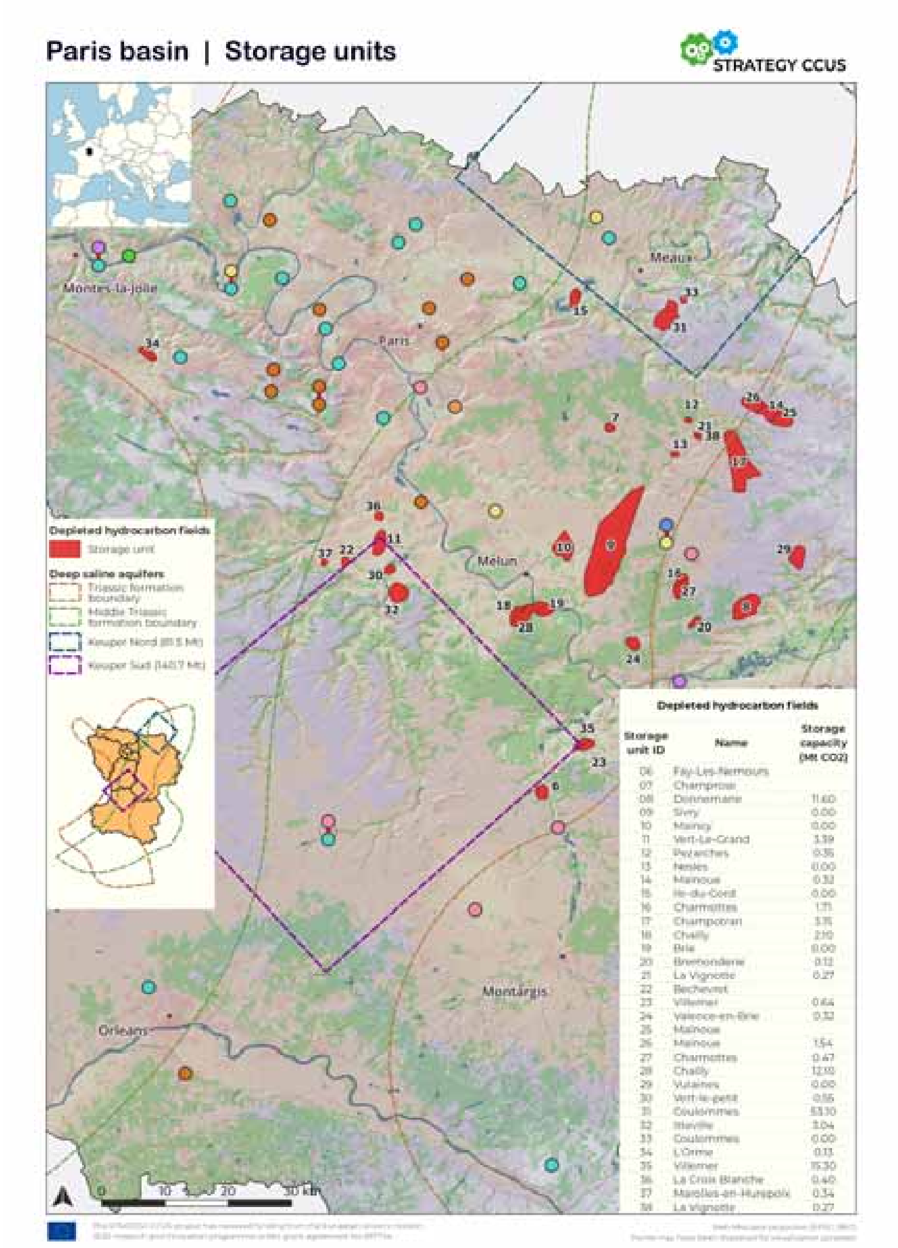
3.1 Paris Basin Region - France

Geographical location

The Paris basin, as studied in the STRATEGY CCUS project, is located in the center-northern part of France. It is located around the French capital - Paris- and it covers the administrative region of the Ile-de-France and the Loiret departments. It is the most populated region of France with more than 12 million inhabitants (20% of the French population).



https://www.strategyccus.eu/sites/default/files/Paris_basin/index.html

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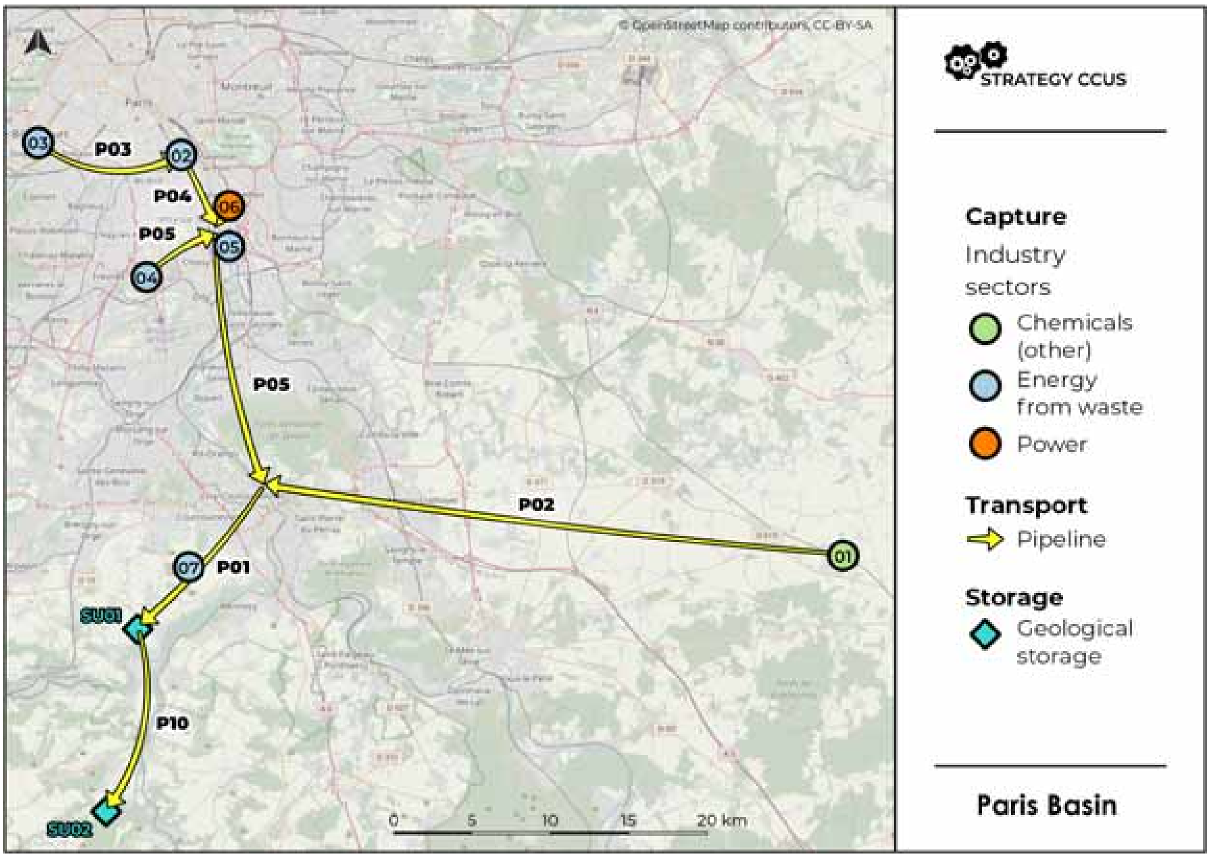
Scenario Map of CCUS at 2050

Emissions of CO_2 in the Paris basin amounted to 6 Mt in 2019. However, this quantity is split into more than forty emitters widespread around the Paris region. Many sites are in dense urban areas with few left spaces for capture installations. Most of them are small emitters, which raises additional challenge for capture process and its economic feasibility. Only 17 sites emit more than 90 kt/y of CO_2, among them 6 emitters exceeded 350 kt/y in 2019: the Grandpuits refinery (541 kt/y), the Grandpuits fertilizer plant (646 kt/y), the waste incineration plants in Saint-Ouen (416 kt), Ivry (572 kt/y) and Issy-les-Moulineaux (384 kt/y), and two heating installations in Saint-Ouen (522 kt/y).

The short-medium timeframe of CCUS deployment is 2025-2035. In 2027, emissions from the Grandpuits fertilizers plant (FR1.ES002) is planned to be stored in a geological reservoir in the southern part of the Paris basin region (Chailan) and the construction of a hub starts to prepare transport of CO_2 from the Paris agglomeration towards the Keuper Sud storage units. By 2032, emissions from the 2 largest waste plants (FR1.ES.003 and FR1.ES.004) in the South of Paris are captured, transported southwards, and stored in the storage unit the Chailan (FR1.SU.001)



https://www.strategyccus.eu/sites/default/files/PB/PB.html

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Key Performance Indicators – main scenario from 2026 to 2050

In the Paris basin scenario, 5 emitters belong to the waste industry, with a total of 18.2 Mt CO_2 captured by 2050. This includes 9.1 Mt CO_2 from biomass. From 2037 (year when all 5 waste-to-energy plants have installed capture) until 2050, the yearly quantity of CO_2 captured is 1.35 Mt/y, including 0.67 Mt/y from biomass. If the waste-to-energy sector is considered as BECCS by French National Low Carbon Strategy (SNBC [**Erreur ! Source du renvoi introuvable.**]) the Paris basin scenario could contribute to 7% of the BECCS objectives for 2050.

Strategy CCUS Region KPIs (Discounted)

Analysis of the CCS system

Total CCS value chain	
CCS value chain (€/tCO2 avoided)	-39,4
Total CAPEX per block	**-9,2**
Cost of Capture (€/tonCO2 avoided)	-4,2
Cost of Transport (€/tonCO2 avoided)	-0,7
Cost of Storage (€/tonCO2 avoided)	-4,3
OPEX per block	**-30,2**
Cost of Capture (€/tonCO2 avoided)	-20,3
Cost of Transport (€/tonCO2 avoided)	-0,3
Cost of Storage (€/tonCO2 avoided)	-9,6
Transport cost (€/tonCO2 transported)	-1,0
Utilisation (income from CO2 sales) (M€)	0,0
EUA/ETS credit savings in the region (M€)	2581,2

Analysis of CO2 volumes (Mt)

Total CO2 Captured	29,8
CO2 utilized	0,0
CO2 for mineralization (perm. avoided)	0,0
Stored	29,8
Total emitted with CCS	10,4
Total avoided emission	29,7
BIO CO2 captured, neg. Emissions	9,1
Total CO2 fed into transport network	**30**
CCUS National Objectives	320
Share in national objectives	9,3 %

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Analysis of ETS allowances

EU ETS parameters	
Price of allowances in 2025 (€/tonCO2)	70
Price of allowances in 2045 (€/tonCO2)	212
Whole regional expense without CCUS:	
ETS costs without CCUS (M€)	3 566,9
Whole region expense with CCUS	
ETS costs with CCUS, remaining emissions (M€)	985,7
Cost of CCUS (M€)	1 169,3
TOTAL costs with CCUS (M€)	**2 154,9**
Cost difference, with minus without CCUS (M€)	**-1 412,0**
Average yearly energy need, TWh/year	**1,04**
Peak energy need, TWh/year	**1,62**
Breakeven CO2 price (€/tonCO2)	42
First year of profit	2028

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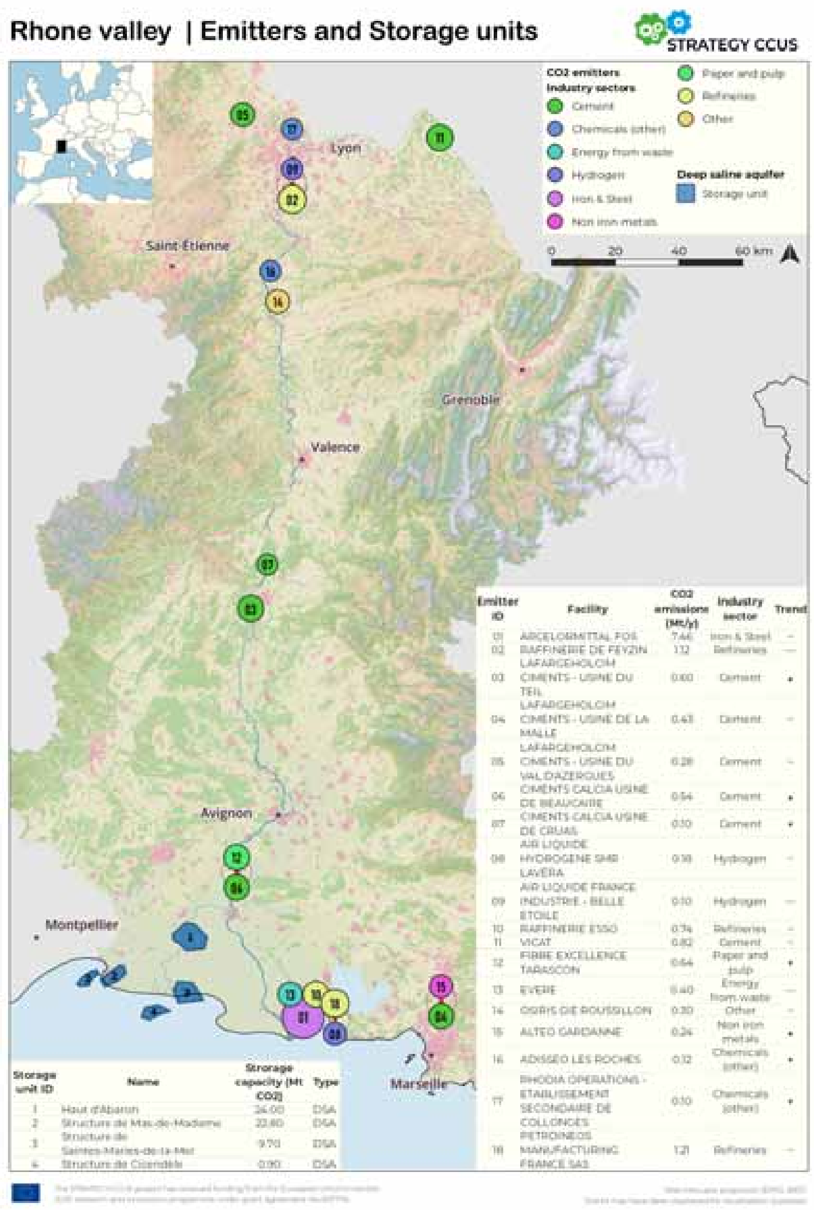
3.2 Rhône valley – France

Geographical location

The Rhône valley is in Southeast of France, stretched from central France towards the Mediterranean Sea. It is an area of 300 km long on both side of the Rhône River. The Rhône corridor links Marseille and Lyon, which are respectively the 2nd and 3rd biggest cities of France. The port of Marseille is France's main trading seaport and could offer a shipping route to CO_2.



https://www.strategyccus.eu/project-outputs/web-maps/mapping-potential-wp2

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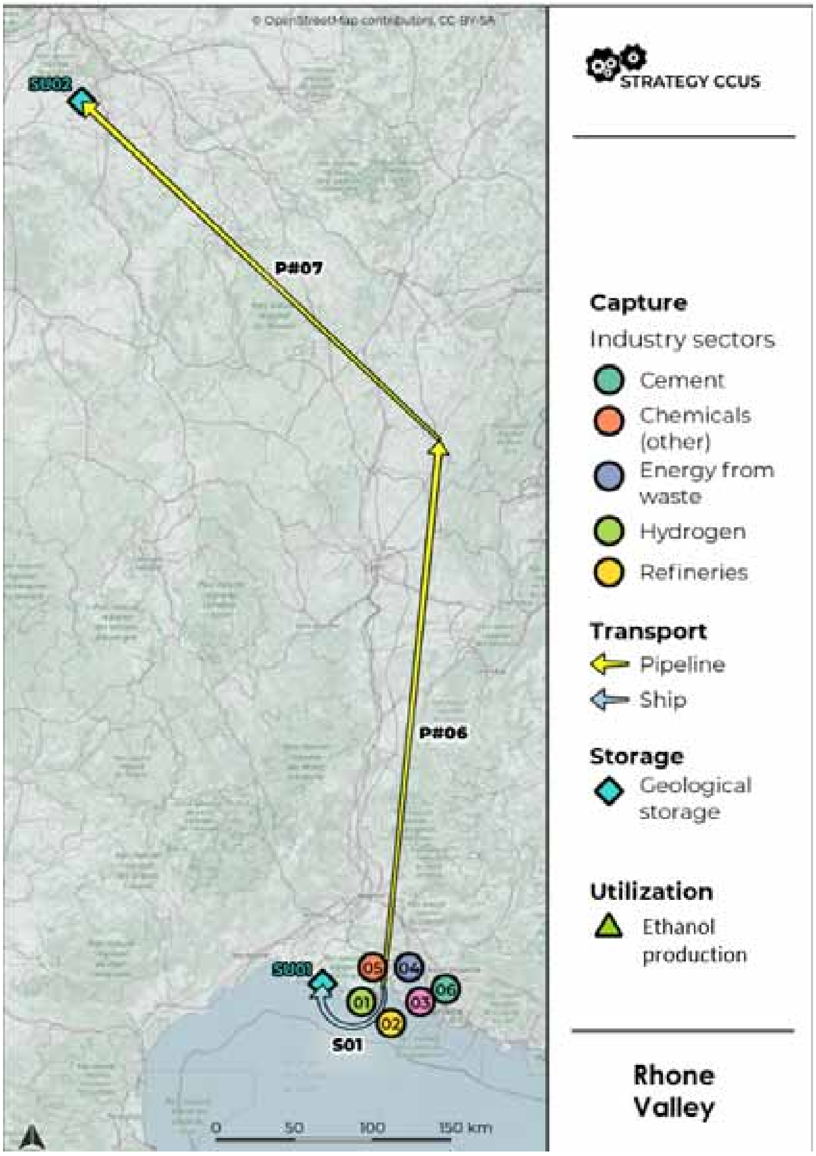
Scenario Map of CCUS at 2050

The choice of sites to be selected for CO_2 capture is based on 3 criteria: emission level, industry sector and location. Plants that emit less than 200 000 tonnes of CO_2 per year being first disregarded, emphasis is placed on industrial sectors responsible for biggest CO_2 emissions i.e., iron and steel, cement, and refining. The main long-term scenario for Rhône valley is characterized using two CO_2 storages from 2030 to 2050.



https://www.strategyccus.eu/sites/default/files/RV/RV.html

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Key Performance Indicators – main scenario from 2026 to 2050

The long-term main scenario for Rhône valley covers the 2026-2050 period. 50.5 Mt of CO_2 are captured over this period, of which 29.4 Mt are stored and 21.1 are used to produce ethanol. CO_2 captured in Rhône valley represents about 10% of what is planned by the SNBC.

Strategy CCUS Region KPIs (Discounted)

Analysis of the CCS system

Total CCS value chain	
CCS value chain (€/tCO2 avoided)	-42
Total CAPEX per block	**-12**
Cost of Capture (€/tonCO2 avoided)	-8
Cost of Transport (€/tonCO2 avoided)	-1
Cost of Storage (€/tonCO2 avoided)	-3
OPEX per block	**-29**
Cost of Capture (€/tonCO2 avoided)	-18
Cost of Transport (€/tonCO2 avoided)	-6
Cost of Storage (€/tonCO2 avoided)	-6
Transport cost (€/tonCO2 transported)	-7
Utilisation (income from CO2 sales) (M€)	2 147
EUA/ETS credit savings in the region (M€)	2 104

Analysis of CO2 volumes (Mt)

Total CO2 Captured	50,5
CO2 utilized	21,1
CO2 for mineralization (perm. avoided)	0,0
Stored	29,4
Total emitted with CCS	228,2
Total avoided emission	29,3
BIO CO2 captured, neg. Emissions	2,2
Total CO2 fed into transport network	**29,4**
CCUS National Objectives	320
Share in national objectives	9,2 %

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Analysis of ETS allowances

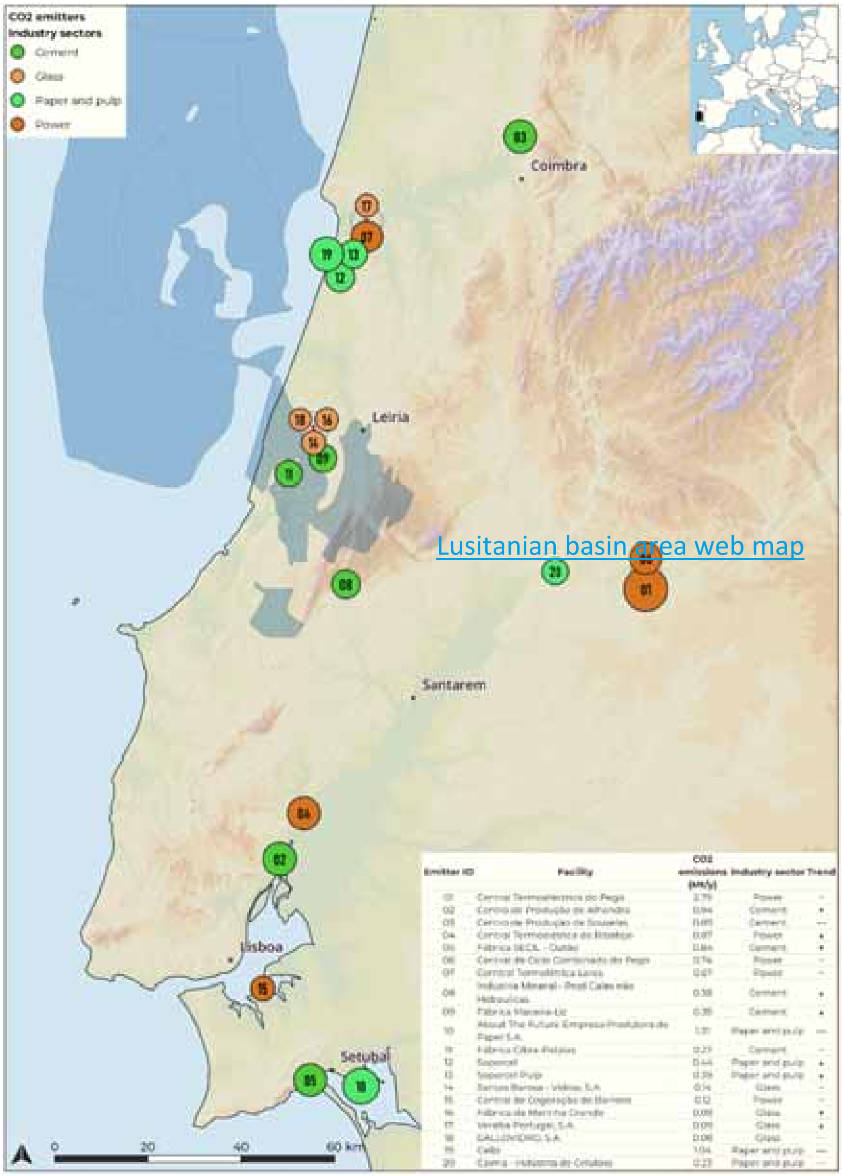
EU ETS parameters	
Price of allowances in 2025 (€/tonCO2)	70
Price of allowances in 2045 (€/tonCO2)	212
Whole regional expense without CCUS:	
ETS costs without CCUS (M€)	18 612
Whole region expense with CCUS	
ETS costs with CCUS, remaining emissions (M€)	16 509
Cost of CCUS (M€)	1 225
TOTAL costs with CCUS (M€)	**17 734**
Cost difference, with minus without CCUS (M€)	**-879**
Average yearly energy need, TWh/year	**8,7**
Peak energy need, TWh/year	**11,0**
Breakeven CO2 price (€/tonCO2)	44

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

3.3 Lusitania Basin – Portugal

Geographical location

The Lusitanian basin area studied in the Strategy CCUS project is in the western central territory of Portugal, covering both the mainland and the continental shelf. The area extends latitudinally from Souselas up to Outão covering the NUTS III regions of Coimbra, Leiria, Médio Tejo, Oeste, Lezíria do Tejo and Lisbon Metropolitan Area (Figure 3-1).



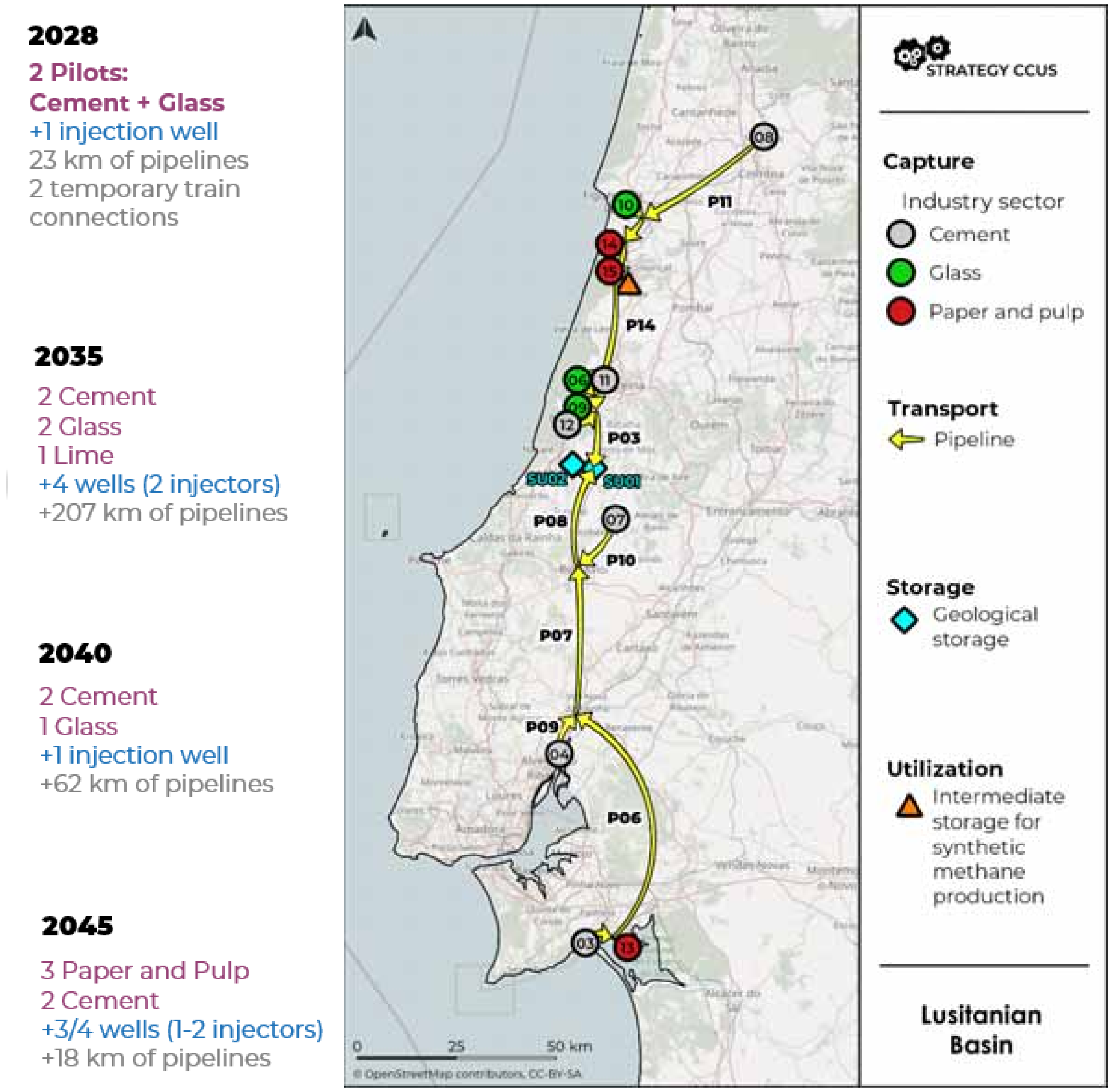
[Lusitanian basin area web map]

The major industries in the region include cement, lime, glass, paper and pulp, ceramics and energy (power and heat production) (Figure 3-1). From the 68 industrial emission sites identified in the region, only 20 were considered as potential targets for CO_2 capturing, with fossil CO_2 emissions ranging from 0.08 Mt/y to 2.79 Mt/y. The joint emissions from those twenty sources were in 2018 12.7 MtCO2/y, representing 97% of total emissions in the region and 42% of the national stationary CO_2 emissions. Meanwhile, the main emitter in the region, Pego coal-fired power plant was decommissioned in 2021. Storage capacity was identified both onshore and offshore (Figure 5). While the onshore promising area only comprise geological formations from Upper Triassic as potential reservoirs, two different potential reservoir types are considered in the offshore area (from Upper Triassic and Lower Cretaceous). The theoretical storage capacity is estimated to be above 0.7 Gt CO_2, with the resource maturity of onshore and offshore units being classified, as Tier 2 and Tier 1, respectively.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Scenario Map of CCUS at 2050

The Lusitanian basin main scenario considers four temporal stages. A first period 2028-2035 for pilots units with capture in two emitters and three subsequent periods starting in 2035, 2040 and 2045 with progressive deployment of capture in several emitters. In the final fourth stage it considers capture in thirteen emitters (in cement, lime, glass and paper and pulp industries), injection in two side-by-side onshore storage units and CO_2 transport by newly constructed dedicated pipelines totaling around 310 km of length.



[Lusitanian basin main scenario web map link]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Key Performance Indicators – main scenario from 2028 to 2050

In total 93 $MtCO_2$ are expected to be captured until 2050, amounting to 66% of the national CO_2 emissions reduction objective, from which 60.5 Mt are to be stored and 32.5 Mt are to be utilized to produce synthetic methane, in connection with the National Hydrogen Strategy. The cost of the complete CCS value chain is estimated at 72 €/t of CO_2 avoided, with the capture process representing the highest share of the costs (around 64 €/tCO2 avoided). The total CAPEX and OPEX costs, discounted and corrected for inflation, for the main scenario amount to 4,333 million of euros.

Strategy CCUS Region KPIs (Discounted) Main DECARB

Analysis of the CCS system

Total CCS value chain	
CCS value chain (€/tCO2 avoided)	-72
Total CAPEX per block	**-27**
Cost of Capture (€/tonCO2 avoided)	-24
Cost of Transport (€/tonCO2 avoided)	-1
Cost of Storage (€/tonCO2 avoided)	-2
OPEX per block	**-45**
Cost of Capture (€/tonCO2 avoided)	-40
Cost of Transport (€/tonCO2 avoided)	-1
Cost of Storage (€/tonCO2 avoided)	-4
Transport cost (€/tonCO2 transported)	-1.2
Utilisation (income from CO2 sales) (M€)	3876.0
EUA/ETS credit savings in the region (M€)	3984.7

Analysis of CO2 volumes (Mt)

Total CO2 Captured	93.0
CO2 utilized	32.5
CO2 for mineralization (perm. avoided)	0.0
Stored	60.5
Total emitted with CCS	28.2
Total avoided emission	60.2
BIO CO2 captured	32.3
Total CO2 fed into transport network	**93**
CCUS National Objectives	91
Share in national objectives	66.2 %

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Analysis of ETS allowances

EU ETS parameters	
Price of allowances in 2025 (€/tonCO2)	70
Price of allowances in 2045 (€/tonCO2)	212
Whole regional expense without CCUS:	
ETS costs without CCUS (M€)	10 651.8
Whole region expense with CCUS	
ETS costs with CCUS, remaining emissions (M€)	6 667.0
Cost of CCUS (M€)	4 333.2
TOTAL costs with CCUS (M€)	**11 000.2**
Cost difference, with minus without CCUS (M€	**348.0**
Average yearly energy need, TWh/year	**3.34**
Peak energy need, TWh/year	**10.32**
Breakeven CO2 price (€/tonCO2)	70
First year of profit	2040

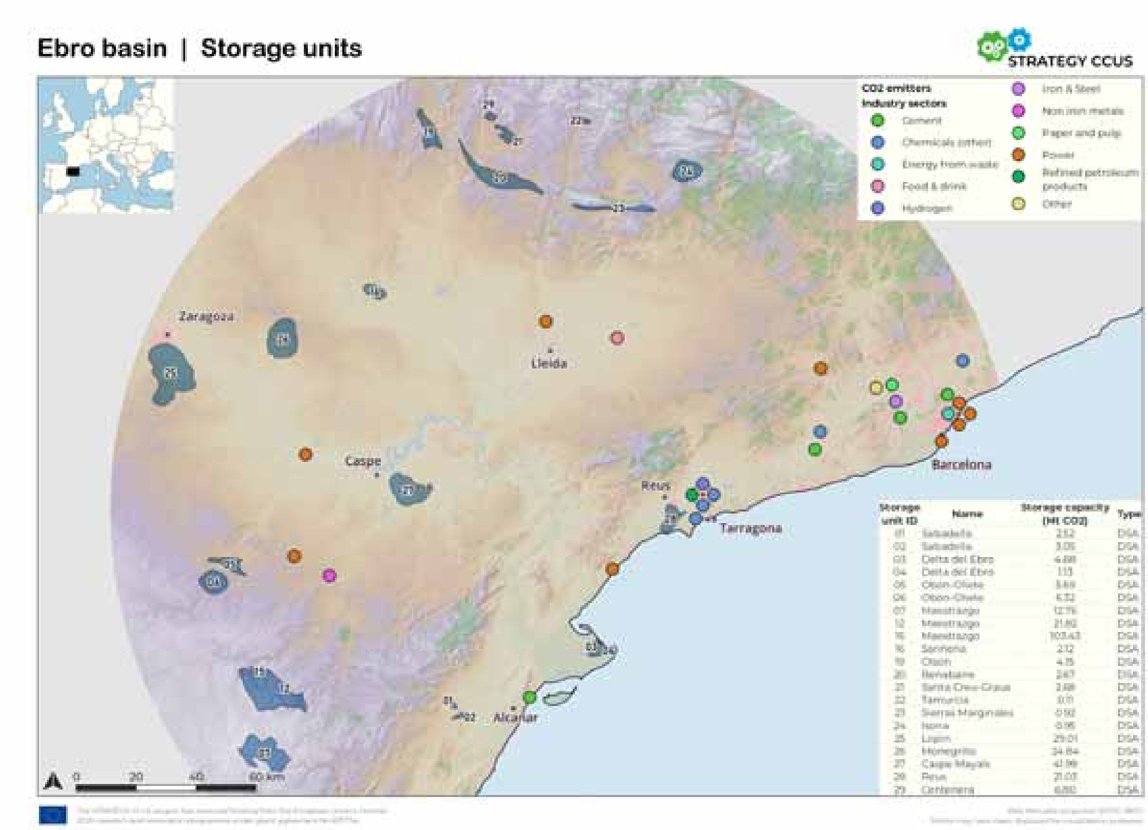
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

3.4 Ebro Basin – Spain

Geographical location

Ebro Basin is located at North-East of Spain, focus on Tarragona industrial area and a 150 km radio on land. It covers Tarragona and Barcelona areas in Comunidad Autónoma (C.A.) de Cataluña; South of Zaragoza and Teruel (C.A. Aragón); and North of Castellón (C.A. Valencia).

This area has been selected based on the presence of important CO2 emitting point sources, the identification of geological structures with storage potential, and the existence of a transport network inside the region and with possibilities of connecting the area with other national and international areas. Tarragona area is also known for its well balance between a strong industry, agriculture, and tourisms development which was considered a plus.

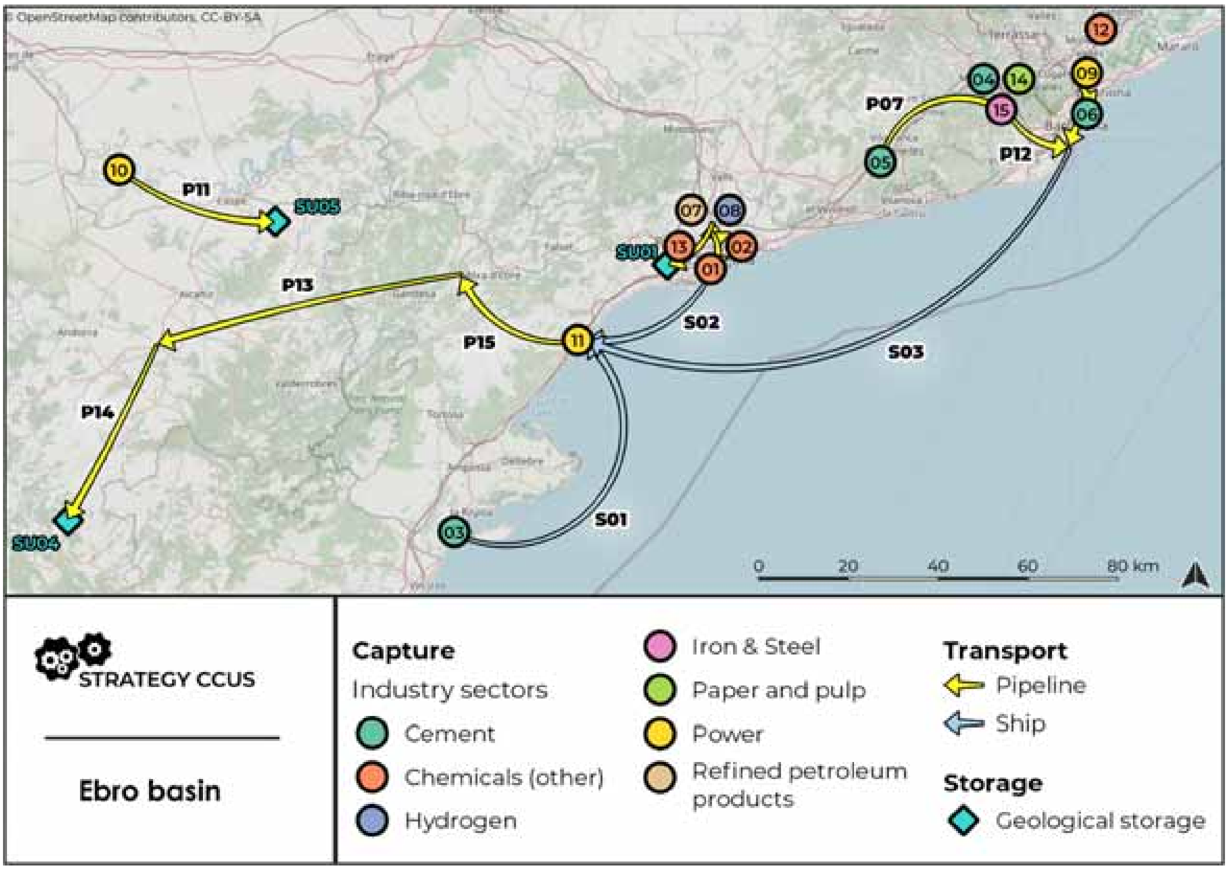


https://www.strategyccus.eu/sites/default/files/Ebro_basin/index.html

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Scenario Map of CCUS at 2050

The base scenario was built with the objective of reach the most extensive CO_2 network for capturing in the region but limited by the potential storage of the area. A total of 15 emitters (mainly chemicals, cement industry and power generation) are combined in two industrial hubs and one standalone. The CO_2 storage starts at 2027 in Reus storage site, next to Tarragona cluster as a type of pilot, with a total of 10 Mtonnes stored, followed by Maestrazgo storage site, with more than 100 Mtonnes capacity, as main storage site of Ebro basin region. The standalone case, due to its distance to the main storage site and estimated cost, has a dedicated storage site 30 km away, Caspe. Transport combines pipeline, ships and trucks depending on needs.



https://www.strategyccus.eu/sites/default/files/EB/EB.html

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Key Performance Indicators – main scenario from 2027 to 2050

The results of the techno-economic evaluation for Ebro Basin based on the Base scenario (15 emitters and 3 storage sites), considering discounted to 2021 values, presents a total CO_2 captured of almost 70 Mtonnes, I.e., 50% of total CO2 produced in the area, and with estimated total cost of 93 €/CO2 tonne avoided. Considering obtained breakeven of 85 €/CO2 tonne avoided, really close of the total cost obtained and the possibilities for the scenario optimization, these results bring us a positive potential for CCUS Tecnologies implementation in the Ebro Basin.

Analysis of the CCS system

Total CCS value chain	
CCS value chain (€/tCO2 avoided)	-93
Total CAPEX per block	-27
Cost of Capture (€/tonCO2 avoided)	-22
Cost of Transport (€/tonCO2 avoided)	-4
Cost of Storage (€/tonCO2 avoided)	-1
OPEX per block	-66
Cost of Capture (€/tonCO2 avoided)	-39
Cost of Transport (€/tonCO2 avoided)	-22
Cost of Storage (€/tonCO2 avoided)	-4
Transport cost (€/tonCO2 transported)	-26,9
Utilisation (income from CO2 sales) (M€)	459,3
EUA/ETS credit savings in the region (M€)	4456,8

Analysis of CO2 volumes (Mt)

Total CO2 Captured	69,4
CO2 utilized	3,9
CO2 for mineralization (perm. avoided)	1,1
Stored	65,5
Total emitted with CCS	153,1
Total avoided emission	66,3
BIO CO2 captured, neg. Emissions	1,0
Total CO2 fed into transport network	**66**
CCUS National Objectives	200
Share in national objectives	33,2 %

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Analysis of ETS allowances

EU ETS parameters	
Price of allowances in 2025 (€/tonCO2)	70
Price of allowances in 2045 (€/tonCO2)	212
Whole regional expense without CCUS:	
ETS costs without CCUS (M€)	18.603,5
Whole region expense with CCUS	
ETS costs with CCUS, remaining emissions (M€)	14.146,7
Cost of CCUS (M€)	6.150,3
TOTAL costs with CCUS (M€)	**20.297,0**
Cost difference, with minus without CCUS (M€)	**1.694,0**
Average yearly energy need, TWh/year	**6,36**
Peak energy need, TWh/year	**13,60**
Breakeven CO2 price (€/tonCO2)	85
First year of profit	NO APPLY

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3.5 North of Croatia – Croatia

Geographical location

Northern Croatia region considered in the STRATEGY CCUS project extends from the Dinaric Alps on the south western border to state border toward North and East. Geologically, it belongs to the Pannonian basin system, which is well-explored through long history of hydrocarbon exploitation in Croatia, meaning that the infrastructure including the transport network is rather developed in this area. The hydrocarbon fields overlap those of the deep saline aquifers (Figure 3-2), since many of them are rooted in the same Sava stratigraphic group. Additionally, in this part of Croatia the emitters are scattered, and their clustering might be feasible considering their individual emissions. All this makes this area a logical choice for developing CO2 capture, utilization, and storage scenarios.

Figure 3-2: Industry sector emitters and potential storage units in the Northern Croatia region with two emitters outside of the region

(https://www.strategyccus.eu/sites/default/files/Northern_Croatia/index.html#8/46.183/16.826)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Scenario Map of CCUS at 2050

After considering two clustering options regarding the emitters and storage units' geographical distribution, the Eastern cluster was chosen for further scenarios development. The main long-term scenario (Figure 3-3) includes three emitters and three storage units (2 depleted hydrocarbon fields and one aquifer). One of the two hydrocarbon fields will be subjected to EOR CO2 utilization scheme in one part of the observed period, after which it will be used for pure storage.

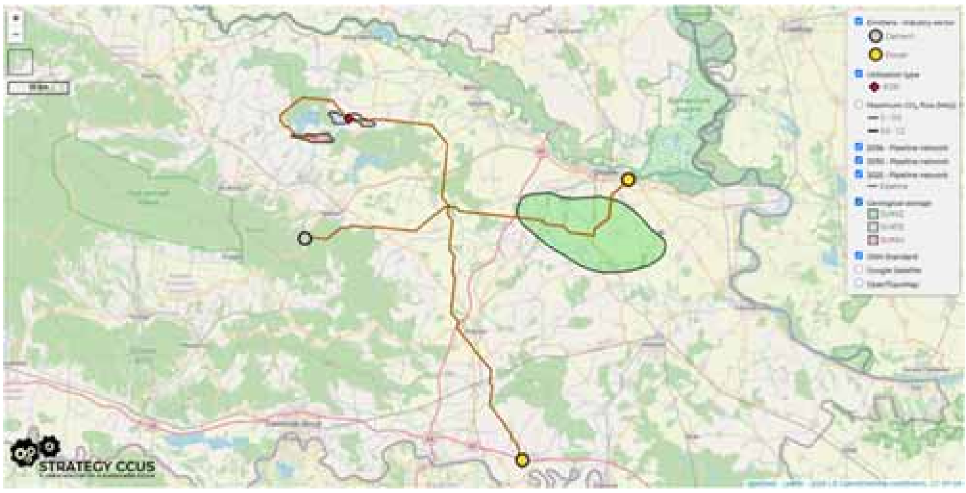

Figure 3-3: The Northern Croatia main long-term scenario concept (https://www.strategyccus.eu/sites/default/files/NC/NC.html#10/45.4395/18.4281)

All CO_2 transport (Figure 3-4) is foreseen to be via 7 pipelines with the overall length of 148 km, with most of the pipelines carrying the captured CO2 to hubs, and one of them directly to one of the storage units. It is assumed that after 2050 the whole infrastructure remains in place for further use.

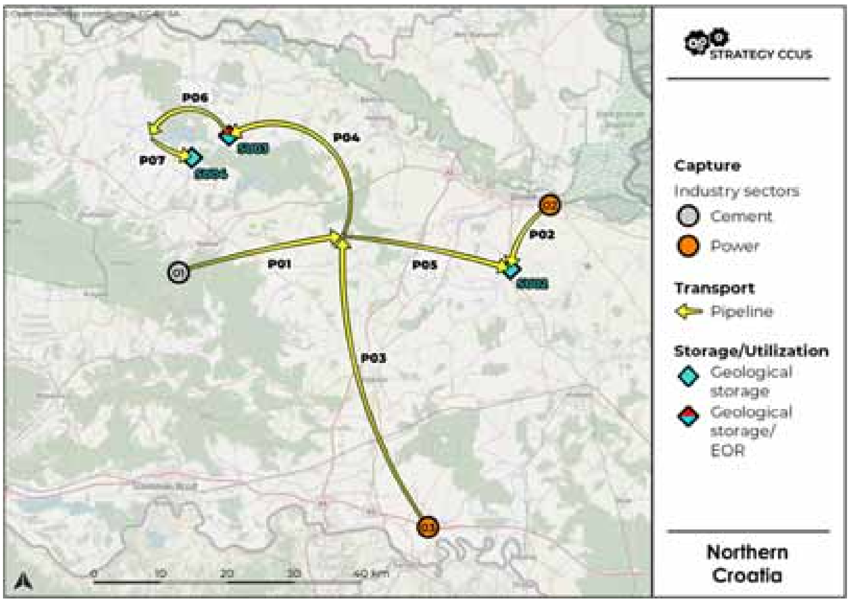

Figure 3-4: The Northern Croatia main long-term scenario transport scheme

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Key Performance Indicators – main scenario from 2025 to 2050

The long-term main scenario for Northern Croatia covers the 2025-2050 period. Over this period 29.8 Mt of CO_2 is to be captured, of which 1.1 Mt would be used for enhanced oil recovery and 27.1 Mt would be stored in depleted hydrocarbon fields and one aquifer. Storage part of the chain has the biggest share in overall costs (55%), while capture accounts for 40%, and transport for only 5% (Figure 3-5).

This result of unrealistically low capturing costs can be explained by low operating costs compared to storage operating costs (which may be ascribed to very small distance between emitters and storage sites, and low initial investment, because the most of infrastructure already exists; also, CO_2-EOR site started with operation very early, and was optimised for CO_2 storage and not for oil recovery), and this resulted in the main long-term scenario being profitable even under the current EU ETS price of CO_2.

Strategy CCUS Region KPIs (Discounted)

Analysis of the CCS system

Total CCS value chain	
CCS value chain (€/tCO2 avoided)	-27
Total CAPEX per block	**-11**
Cost of Capture (€/tonCO2 avoided)	-5
Cost of Transport (€/tonCO2 avoided)	-1
Cost of Storage (€/tonCO2 avoided)	-4
OPEX per block	**-16**
Cost of Capture (€/tonCO2 avoided)	-5
Cost of Transport (€/tonCO2 avoided)	-1
Cost of Storage (€/tonCO2 avoided)	-10
Transport cost (€/tonCO2 transported)	-1,4
Utilisation (income from CO2 sales) (M€)	78,6
EUA/ETS credit savings in the region (M€)	1879,9

Analysis of CO2 volumes (Mt)

Total CO2 Captured	29,8
CO2 utilized	1,1
CO2 for mineralization (perm. avoided)	0,0
Stored	27,1
Total emitted with CCS	4,4
Total avoided emission	28,5
BIO CO2 captured, neg. Emissions	0,0
Total CO2 fed into transport network	**30**
CCUS National Objectives	200
Share in national objectives	14,2 %

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Analysis of ETS allowances

EU ETS parameters	
Price of allowances in 2025 (€/tonCO2)	70
Price of allowances in 2045 (€/tonCO2)	212
Whole regional expense without CCUS:	
ETS costs without CCUS (M€)	1 638,7
Whole region expense with CCUS	
ETS costs with CCUS, remaining emissions (M€)	-241,1
Cost of CCUS (M€)	770,4
TOTAL costs with CCUS (M€)	**529,3**
Cost difference, with minus without CCUS (M€)	-1 109,0
Average yearly energy need, TWh/year	1,15
Peak energy need, TWh/year	1,35
Breakeven CO2 price (€/tonCO2)	30
First year of profit	2027

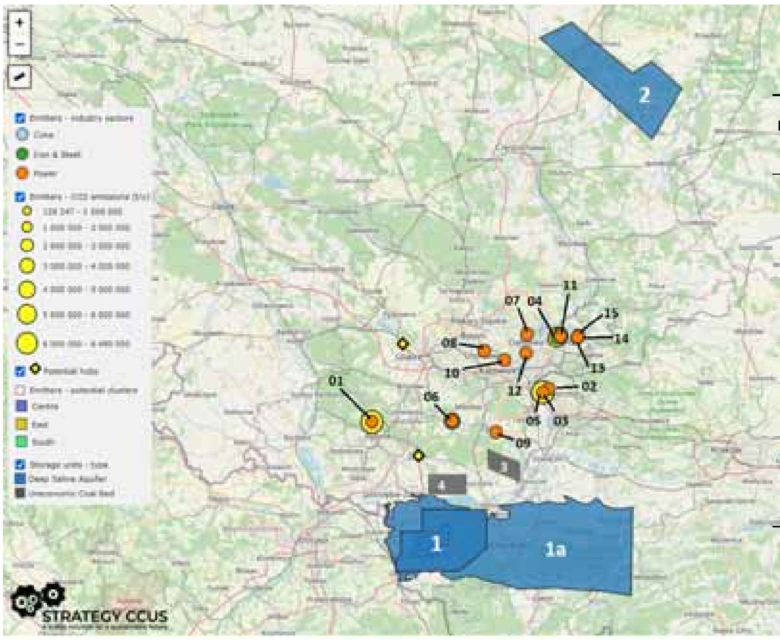
Figure 3-5: Key performance indicators for the Northern Croatia main long-term scenario

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

3.6 Upper Silesia – Poland

Geographical location

The Silesian Voivodeship is located in the southern part of Poland, adjacent to the following voivodeships: Opole, Łódź, Świętokrzyskie and Małopolskie, and to the south it borders with the Moravian-Silesian Region in the Czech Republic and the Žilina Region in the Slovak Republic. This is highly urbanized region with an area of 12 333 km^2 (3.9% of the country), population of 4.5 million (11.8% of Poland's population) and population density 366 people/km^2. This is the most industrialized region in Poland, with a strong mining industry (16 coal mines), strong energy sector (about 7 GW of capacity – 20% of installed capacity in utility power plants in Poland) and good infrastructure. On the other hand the region is characterized by rich biodiversity and a high level of forest cover (32.1%). The storage potential is insufficient – total estimated storage capacity in the promising region is about 111.5 Mt.



Emitter ID / industry sector	Facility
01 / Power	PGE GiEK S.A Power Plant 'Rybnik'
02 / Power	Tauron Wytwarzanie S.A. Power Plant Jaworzno III, power plant II
03 / Power	Tauron Wytwarzanie S.A. Power Plant branch Jaworzno III
04 / Iron & steel	ArcelorMittal Poland S.A. Ironworks Arcellor Mittal in Dąbrowa Górnicza (blast furnace, steelworks, sinter plant, lime plant, rolling mill)
05 / Power	**Tauron Wytwarzanie S.A. Power Plant New Jaworzno**
06 / Power	Tauron Wytwarzanie S.A. Power Plant branch Łaziska
07 / Power	Tauron Wytwarzanie S.A. Power Plant branch Łagisza in Będzin
08 / Power	CEZ Chorzów S.A.
09 / Power	**Tauron Ciepło Sp. z o.o. Zakład Wytwarzania Tychy, Combined heat and power plant Tychy**
10 / Power	Tauron Ciepło Sp. z o.o. Combined heat and power plant Katowice
11 / Power	**TAMEH Polska Sp. z o. o. Zakład Wytwarzania Nowa in Dąbrowa Górnicza**
12 / Power	Combined heat and power plant Będzin Sp. z o.o.
13 / Coke plant	JSW Koks S.A. Coke Plant 'Przyjaźń' in Dąbrowa Górnicza
14 / Power	**JSW Koks S.A. Power Plant of Coke Plant 'Przyjaźń' in Dąbrowa Górnicza**
15 / Power	**JSW Koks S.A. Combined heat and power plant of Coke Plant 'Przyjaźń' in Dąbrowa Górnicza**

* The new unit of 910 MW launched in 2021.

Location of the CO2 emitters and storage sites in Upper Silesia, Poland: (1) Upper Silesian Coal Basin (DSA) , (2) Jurrasic Czestochowa District (DSA) , (3) Studzienice-Międzyrzecze site (UCB) , (4) Pawłowice-Mizerów site (UCB)

Śliwińska, A.; Strugała-Wilczek, A.; Krawczyk, P.; Leśniak, A.; Urych, T.; Chećko, J.; Stańczyk, K. Carbon Capture Utilisation and Storage Technology Development in a Region with High CO2 Emissions and Low Storage Potential—A Case Study of Upper Silesia in Poland. Energies 2022, 15, 4495. https://doi.org/10.3390/en15124495

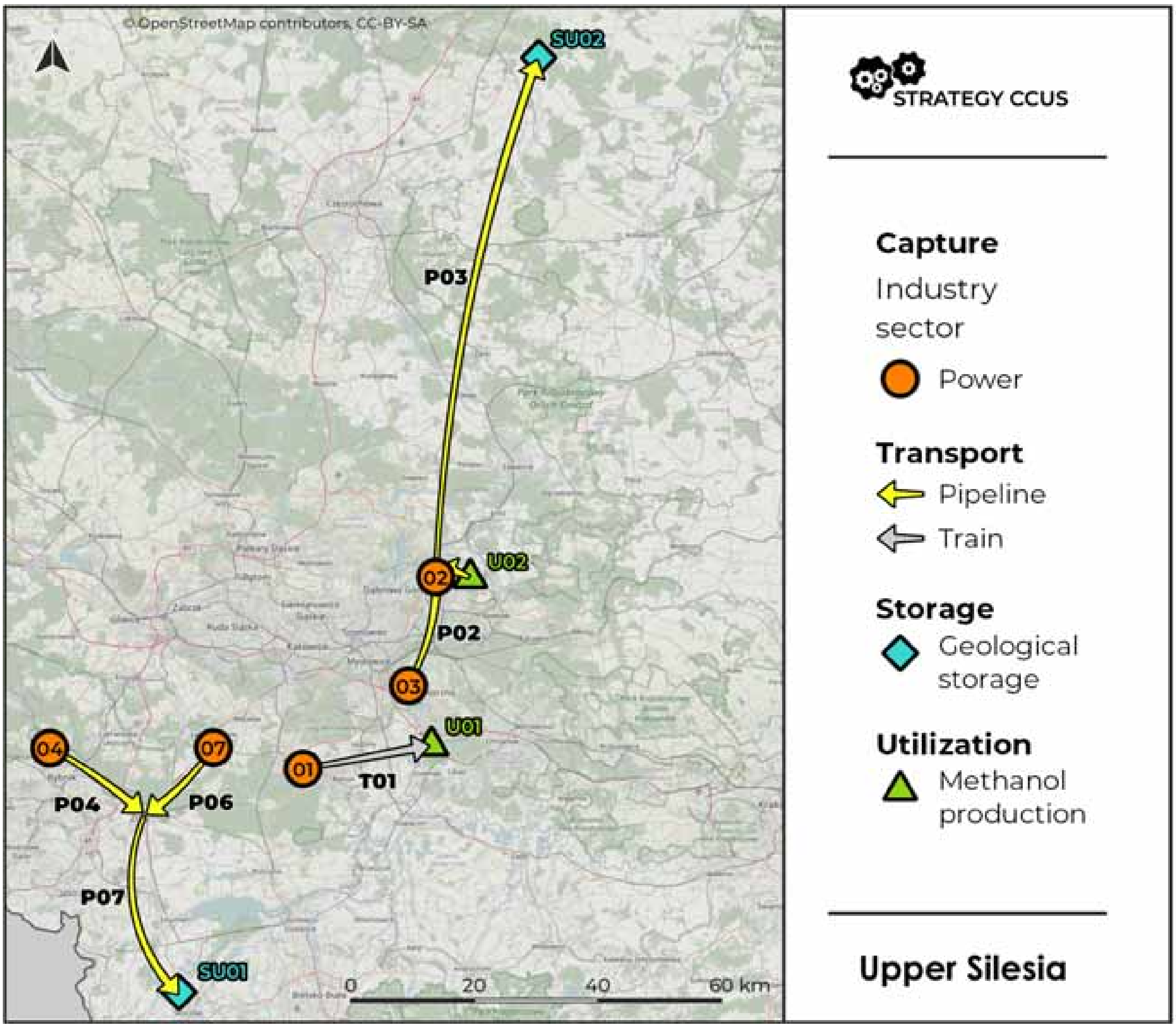
https://www.strategyccus.eu/project-outputs/web-maps/mapping-potential-wp2

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Scenario Map of CCUS at 2050

Although in Upper Silesia there are over 100 carbon dioxide emitters covered by the EU and emitting yearly 33 Mt, over 90% of emissions come from 15 large power facilities, as well as from the coke and metallurgical complexes.

The baseline scenario assumes the capture of carbon dioxide from 7 emitters in 6 installations, use in two methanol plants and transport and injection into two deep saline aquifers (DSA). It is assumed that carbon capture will take place primarily in new power plants. During the construction of the scenario, the following criteria were taken into account: emitter age, available storage capacity, short distance, the possibility of sharing the infrastructure, including the possibility of CO_2 utilisation.



https://www.strategyccus.eu/sites/default/files/US/US.html#9/50.4418/19.1383

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Key Performance Indicators – main scenario from 2025 to 2050

The long-term basic scenario for the Upper Silesia covers the 2025-2050 period. 106.1 Mt of CO_2 is captured over this period, of which 91.4 Mt are stored and 13.2 Mt are used to produce methanol.

Strategy CCUS Region KPIs (Discou

Analysis of the CCS system

Total CCS value chain	
CCS value chain (€/tCO2 avoided)	-25
Total CAPEX per block	**-14**
Cost of Capture (€/tonCO2 avoided)	-11
Cost of Transport (€/tonCO2 avoided)	-1
Cost of Storage (€/tonCO2 avoided)	-3
OPEX per block	**-11**
Cost of Capture (€/tonCO2 avoided)	-6
Cost of Transport (€/tonCO2 avoided)	0
Cost of Storage (€/tonCO2 avoided)	-5
Transport cost (€/tonCO2 transported)	-1,0
Utilisation (income from CO2 sales) (M€)	1328,7
EUA/ETS credit savings in the region (M€)	6151,4

Analysis of CO2 volumes (Mt)

Total CO2 Captured	106,1
CO2 utilized	13,2
CO2 for mineralization (perm. avoided)	0,0
Stored	91,4
Total emitted with CCS	176,4
Total avoided emission	92,3
BIO CO2 captured, neg. Emissions	0,0
Total CO2 fed into transport network	**106**
CCUS National Objectives	
Share in national objectives	

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d)

Analysis of ETS allowances

EU ETS parameters	
Price of allowances in 2025 (€/tonCO2)	70
Price of allowances in 2045 (€/tonCO2)	212
Whole regional expense without CCUS:	
ETS costs without CCUS (M€)	22 184,6
Whole region expense with CCUS	
ETS costs with CCUS, remaining emissions (M€)	16 033,3
Cost of CCUS (M€)	2 344,2
TOTAL costs with CCUS (M€)	**18 377,5**
Cost difference, with minus without CCUS (M€)	**-3 807,0**
Average yearly energy need, TWh/year	**12,25**
Peak energy need, TWh/year	**17,06**
Breakeven CO2 price (€/tonCO2)	29
First year of profit	2029

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

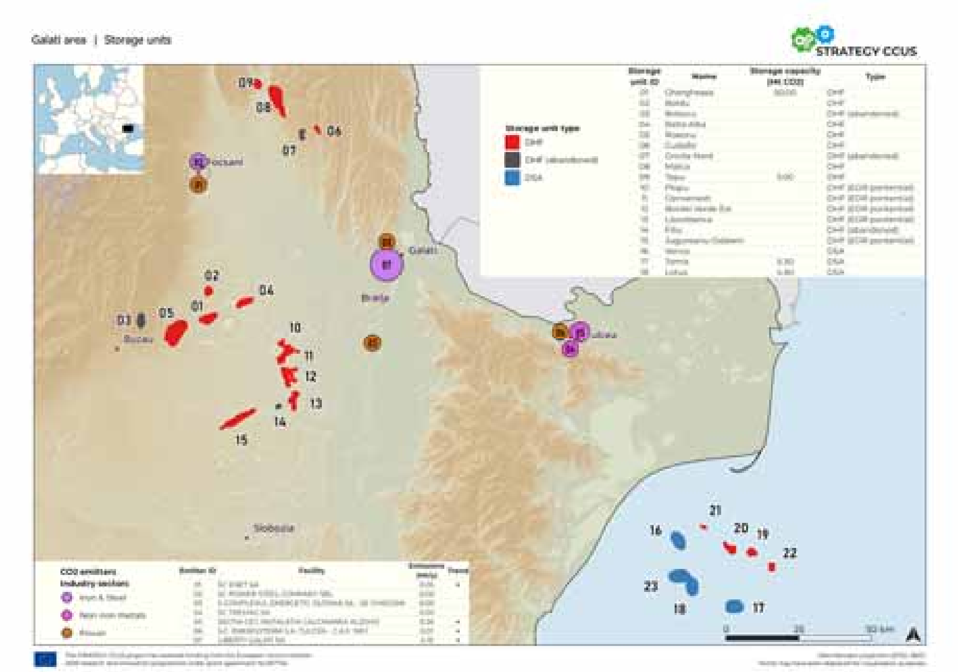
3.7 Galati – Romania

Geographical location

Galați area studied in the Strategy CCUS project is located in the eastern part of Romania and comprises three counties, Galați, Tulcea and Focșani.

From all these counties, Galați has the largest emissions, as Liberty Steele is the largest emitter responsible of more than 93% of the emissions in the area in 2020. The total industrial emissions per country were 31.89 Mt in 2020 and 4.17 Mt in the region.

Eight industrial emission sites were included in the final WP2 data base, and out of these, only three are currently operating in the Galați and Tulcea areas. These are the two sub-clusters where CCUS chains are evaluated within the scenarios.



https://www.strategyccus.eu/sites/default/files/Galati_region/index.html#8/45.070/28.540

The region is in economic decline, a lot of the industrial facilities being closed. Liberty Steel Galați is the only profitable emitter under the current economic circumstances. According to the last national recorded census (2011) in the studied region a yearly population decline of up to 3%/year has also been recorded. The current population accounting will be available most probably at the end of 2022 where a new census was deployed at national level.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Scenario Map of CCUS at 2050

The main scenario for Galati region starts in 2025 when CCUS is implemented for Galati sub-cluster. The deployment of CO2 capture is supposed to be made at two facilities, Liberty Steel Galați and a new gas-fired power plant, a joint venture with the biggest gas producer in the country, Romgaz. This latest emitter is planned to produce electricity and fuel the processes from steel production. For Liberty Steel Galați, only 25% of emissions from 2020 were assumed to be left for CCUS as a result of the increase in efficiency and change of fuel. Tulcea sub-cluster begins operation from 2030 when capture is envisaged from Alum Tulcea (alumina production facility) and Energoterm (heat producer).

The transport modes planned are onshore pipelines for Galati-subcluster and ship transport for Tulcea sub-cluster.

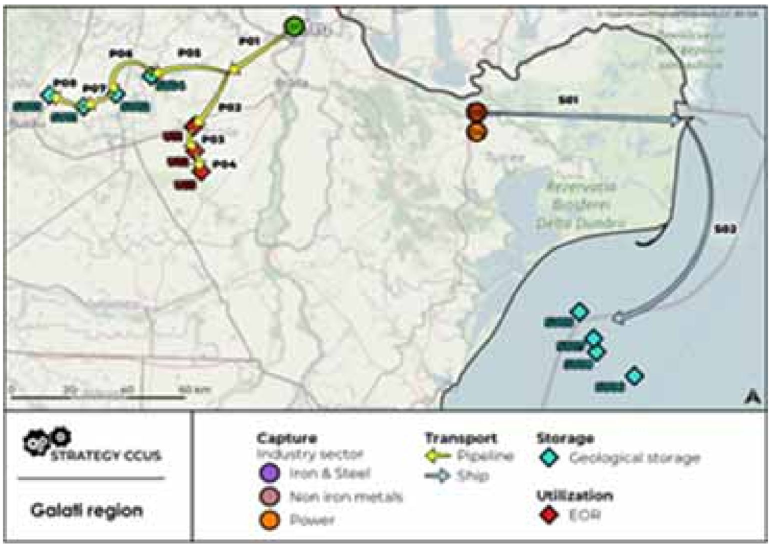
Screening for utilisation options for the region, the only possible use for the captured CO2 was found to be CO2-EOR. In the scenario, 3 oil fields (Oprisenesti, Liscoteanca nad Birdei Verde Est) have been introduced as possible cases, taking the CO2 from Liberty Steel and the new gas-fired power plant.

The total storage capacity considered for the region is 61.73 Mt.

Regarding the storage options, for Galați sub-cluster, only onshore storage was chosen for the scenario,in depleted gas fields (Rosioru, Boldu, Bobocu, Ghergheasa and Balta Alba). Storage was planned to start at the field closest to hub (balta Alba) and then successively to Boldu, Ghergheasa, Roșioru and Bobocu. The development of these storage units and pipelines relies on the capacity estimate in the sense that next storage unit will be opened when the previous one is filled.

The only storage solution considered in this scenario for Tulcea sub-cluster is an offshore deep saline aquifer, Venus. Apart from this, there are other 3 deep saline aquifers (Iris, Lotus, Tomis) which could be used in other scenarios. Initially, storage for this sub-cluster was considered in all of these four sites.

The total storage capacity considered for the entire region is 61.73 Mt. This estimate was made solely on public data.



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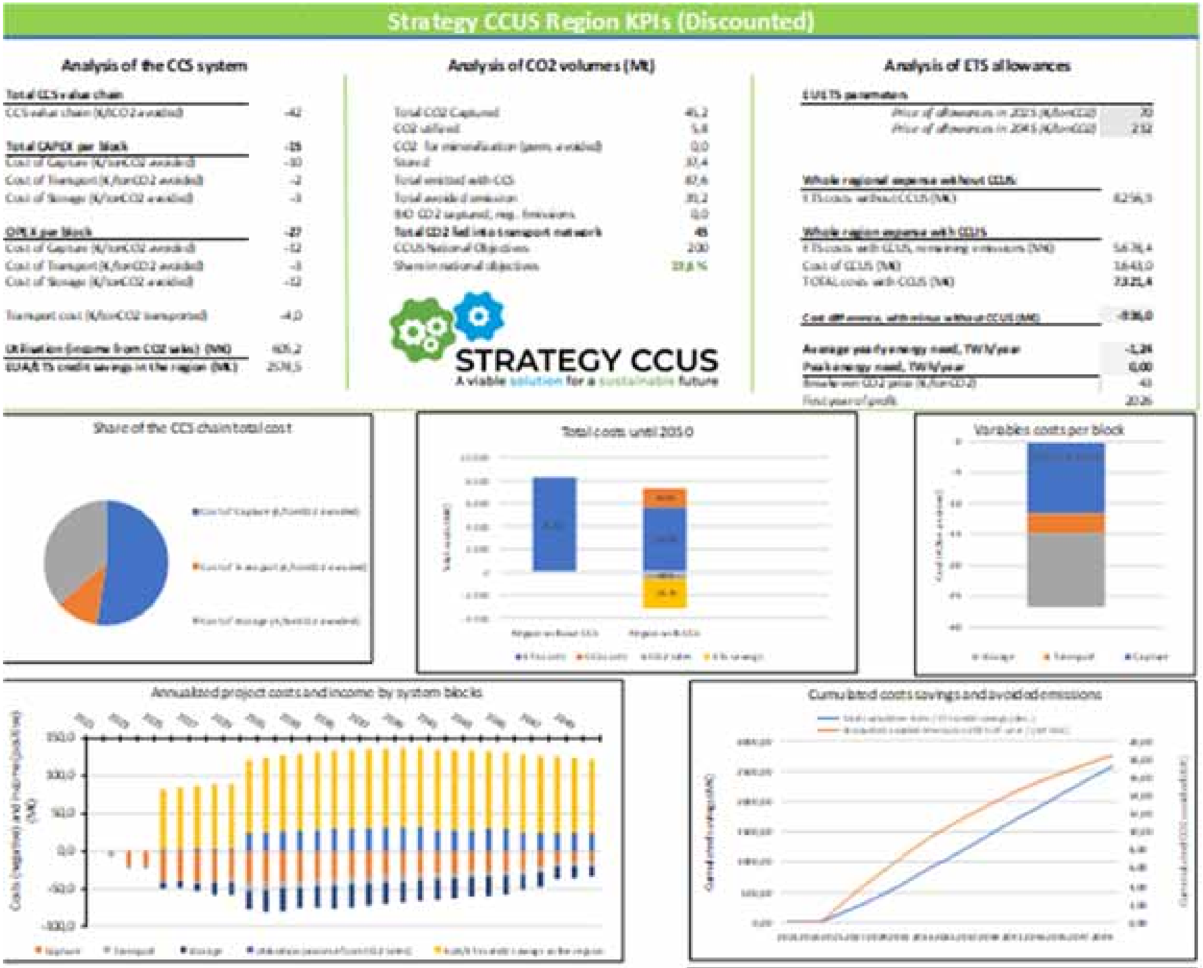
https://www.strategyccus.eu/sites/default/files/GR/GR.html#9/44.8945/28.3415

Key Performance Indicators – main scenario from 2025 to 2050

The KPI's for the entire long-term scenario are presented in Figure below. The total cost of the chain is 42 € /ton of CO2 avoided, 15 € for CAPEX and 27 € for OPEX. The largest share of the costs is for capture. The breakeven CO2 price of the scenario is of 43 €/t CO2 avoided.

The economic results are clearly underestimated. This is due to the fact that only public data was used for the assessment. Real, operator data is needed in order to make an assessment closer to reality.



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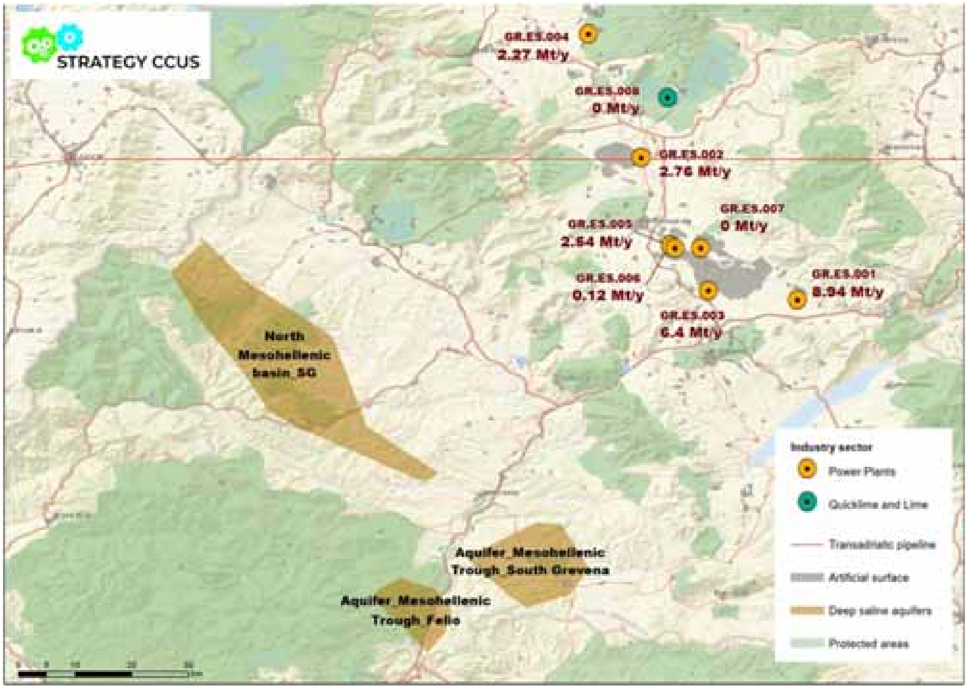
3.8 West Macedonia – Greece

Geographical location

The Mesohellenic Trough is is a piggyback basin of 150 km length and 30 km width. It is located in the middle part of the Hellenic chain (between the Pindos accretionary prism and the Pelagonian upper unit). It is partly located in Northern Greece and partly in Albania and was developed from Middle Eocene to Upper Miocene. The Grevena area, part of the MHT, is suitable for CO_2 storage and comprised by five molassic-type formations. The potential storage sites at the Mesohellenic Trough (MT), correspond to a basin with a length of over 200 km and a width of 30-40 km in northwestern Greece.

In West Macedonia (Greece), CO_2 accounts as one of the largest contributors of greenhouse gas emissions related to the activity of the regional coal power plants located in Ptolemaida. The necessity to mitigate CO_2 emissions to prevent climate change under the Paris Agreement's framework remains an ongoing and demanding challenge.



https://www.strategyccus.eu/sites/default/files/West_Macedonia/index.html

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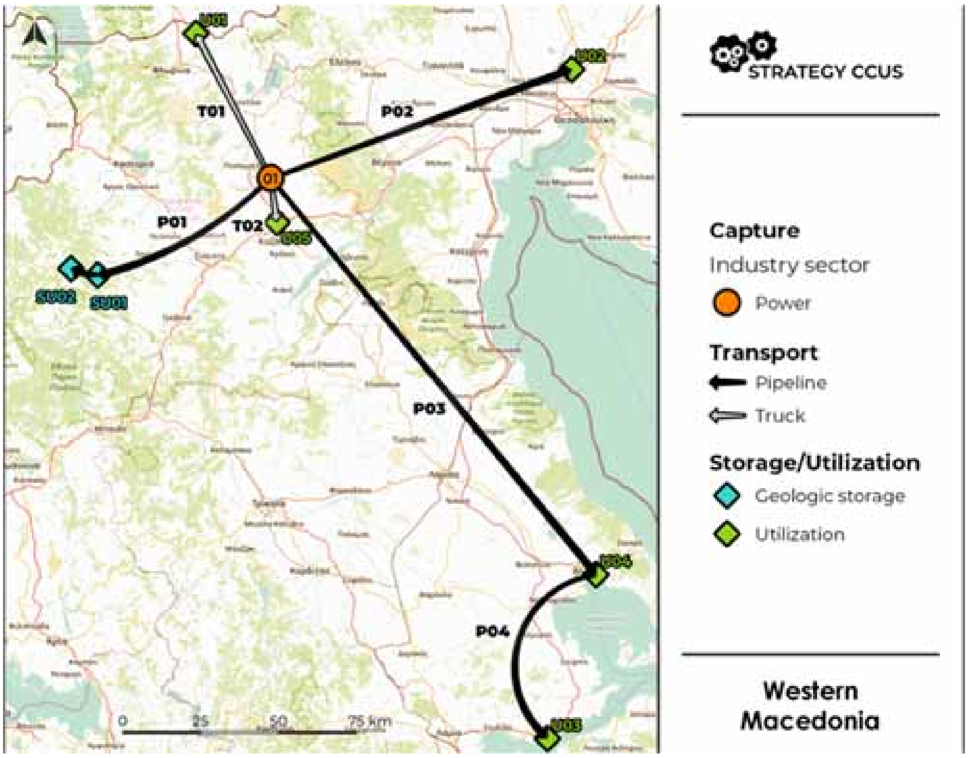
Scenario Map of CCUS at 2050

Regarding the CO_2 utilisation for the long-term scenario, from 2030 to 2050, 3.06 Mt CO_2 pure will be produced, 8.42 Mt e-fuels and 299.3 in mineralisation. Moreover, the maximum CO_2 utilisation will be done from 2036 to 2050. Regarding the storage 4.34 Mton will be stored in Pentalofos, while the total emitted one is 0.02 Mton. At the Eptachori storage unit, in the first five years of the long-term scenario, the CO2 injection level will be high and after 2035, this rate will be gradually decreased until 2040. From 2040 to 2050, the CO_2 injection level will be fixed at 0.1 Mt per year. The avoided CO_2 emissions are about 17 Mt. Simultaneously, the total emitted by carbon capture is only 0.04 Mt.

In the CCS chain total cost, capture has the largest share while storage the smallest one. Moreover, CO2 sales and ETS savings generate regional revenues and reduce significantly total costs. In particular, with the implementation of a long-term scenario, the West Macedonia region will have revenues up to almost 3.8 billion euros gaining from CO_2 sales and ETS savings.



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Key Performance Indicators – main scenario from 2030 to 2050

The long-term main scenario for the West Macedonia region covers the period from 2030 to 2050. This figure below includes the analysis of CCS system, CO_2 volumes and of ETS allowances. Particularly, 39Mt of CO_2 are captured in the long-term scenario, 39Mt are transported, 32 Mt are utilised and 7 Mt are stored. The avoided emission is about 17 Mt of CO_2.

Strategy CCUS Region KPIs (Discounted)

Analysis of the CCS system

Total CCS value chain	
CCS value chain (€/tCO2 avoided)	-36
Total CAPEX per block	**-17**
Cost of Capture (€/tonCO2 avoided)	-11
Cost of Transport (€/tonCO2 avoided)	-4
Cost of Storage (€/tonCO2 avoided)	-2
OPEX per block	**-19**
Cost of Capture (€/tonCO2 avoided)	-13
Cost of Transport (€/tonCO2 avoided)	-6
Cost of Storage (€/tonCO2 avoided)	0
Transport cost (€/tonCO2 transported)	-4.3
Utilisation (income from CO2 sales) (M€)	2841.7
EUA/ETS credit savings in the region (M€)	1053.8

Analysis of CO2 volumes (Mt)

Total CO2 Captured	38.9
CO2 utilized	31.7
CO2 for mineralization (perm. avoided)	10.0
Stored	7.2
Total emitted with CCS	4.3
Total avoided emission	17.2
BIO CO2 captured, neg. Emissions	0.0
Total CO2 fed into transport network	**39**
CCUS National Objectives	200
Share in national objectives	8.6 %

Analysis of ETS allowances

EU ETS parameters	
Price of allowances in 2025 (€/tonCO2)	70
Price of allowances in 2045 (€/tonCO2)	212
Whole regional expense without CCUS:	
ETS costs without CCUS (M€)	2,672.7
Whole region expense with CCUS	
ETS costs with CCUS, remaining emissions (M€)	1,619.0
Cost of CCUS (M€)	613.8
TOTAL costs with CCUS (M€)	**2,232.8**
Cost difference, with minus without CCUS (M€)	**-440.0**
Average yearly energy need, TWh/year	**0.91**
Peak energy need, TWh/year	**1.29**
Breakeven CO2 price (€/tonCO2)	39
First year of profit	2030

STRATEGY CCUS
A viable solution for a sustainable future

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4 Issues to facilitate the deployment of CCUS in STRATEGY CCUS regions

STRATEGY CCUS adopted a multidisciplinary bottom-up approach. Looking at local and regional scale of eight EU member states, STRATEGY CCUS project analysed every aspect involved in the deployment of CCUS: technical, societal, economic and environmental.

A final synthetic analysis of the deployment issues and the possibly way forward for CCUS deployment in the 8 regions were divided into three large groups: techno-economic, social and policies and government factors. Main issues of this analysis are summarized below:

1. Technical readiness level and economy of the CCUS value chain are among key factors for facilitating industry engagement in any industrial process. For techno-economic aspects:
    a. Capture related technologies have few of obstacles
    b. Transport is mostly fine and well-advanced with few obstacles to overcome
    c. Storage is struggling with lack of availability and reliability of data as well as maturation of storage sites in most of the regions
    d. Multisector approach to CCUS is largely fine
    e. Business models and costs are still a large issue for CCS implementation in the regions analysed
2. Social aspects focus on the relevant stakeholders look generally more advanced compared to techno-economic aspects:
    a. Stakeholders that were identified as relevant for CCUS deployment have positive attitude toward CCUS
    b. The liaisons between industry and stakeholders are also advanced in most regions
    c. Society's awareness and knowledge about CCUS technologies are low and present a major bottleneck to work on. In addition, the general awareness of the necessity of climate change mitigation in the general public could also be improved
    d. The negative local impacts of CCUS on the environment present a bottleneck in most regions
    e. The potential of local public resistance needs to be considered carefully for the planning of CCUS in the regions
    f. In contrast, the potential of CCUS to attract new industries including the maintenance or creation of jobs is advanced or moving slowly in all regions
3. Finally, policy / regulations showed many issues as well:
    a. Legal framework and availability of renewable energy are largely fine with some obstacles
    b. Permitting, incentives and transboundary regulations are a major issue

Finally, national and territorial integration of CCUS into strategies varies across the regions from posing obstacles to being fine. None of the 8 regions analysed are free from issues and all of them require future work to be done to facilitate CCUS deployment. Similarly, techno-economic, social and policies and government factors are identified as problematic.

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The list of project publications is available on CORDIS https://cordis.europa.eu/project/id/837754/results

6 Annexes

6.1 List of public deliverables

All public deliverables are available on the project website: https://www.strategyccus.eu/project-outputs. These deliverables are being made available on CORDIS https://cordis.europa.eu/project/id/837754/results.

WP No	Del Rel. No	Title	Nature
WP1	D1.4	Final Project Report	Report
WP1	D1.8	Project Progress Report	Report
WP2	D2.1	Methodologies for cluster development and best practices for data collection in the promising regions	Report
WP2	D2.2	Report with maps on technical CCUS potential (sources, sinks, uses, corridors) in each promising region	Report
WP2	D2.3	Maturity level and confidence of storage capacities estimates in the promising regions	Report
WP3	D3.1	Stakeholder mapping report	Report
WP3	D3.2	Report on scoping on acceptance issues	Report
WP3	D3.3	Report on public acceptance findings	Report
WP3	D3.4	Stakeholder engagement findings: roadmap and final recommendations	Report
WP4	D4.1	Report on data template to build model for Life Cycle Assessment (LCA) and Techno-Economic Assessment (TEA)	Report
WP4	D4.3	Life Cycle Assessment (LCA) and Techno-Economic Assessment (TEA) in three selected promising regions describing processes involved in CCUS, scaled to a common unit	Report
WP4	D4.4	Multi-Regional Input Output (MRIO) analysis of CCUS deployment of three selected promising regions	Report
WP4	D4.5	Cost-effectiveness of storage sites and comparison of promising regions	Report
WP5	D5.2	Report of the business case for each region	Report
WP5	D5.3	Regional economic evaluation Report	Report

WP5	D5.4	National economic evaluation Report	Report
WP5	D5.5	Identification of sustainable cooperation schemes in regional CCS systems	Report
WP5	D5.6	Issues to facilitate the deployment of CCUS	Report
WP5	D5.7	Impact of the scenarios on the EU ETS	Report
WP6	D6.1	Project Communication Strategy	Report
WP6	D6.10	Stakeholder engagement toolbox - Final Version	Other
WP6	D6.4	Data Management Plan - initial	ORDP: Open Research Data Pilot
WP6	D6.5	Data Management Plan - Final	ORDP: Open Research Data Pilot
WP6	D6.6	Project branding and website version 1	Websites, patents filing, etc.
WP6	D6.7	Final version of Project website	Websites, patents filing, etc.
WP6	D6.9	Stakeholder engagement toolbox - Initial Version	Other

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6.2 Glossary (list of abbreviations and Acronyms)

Abbreviation	Description
BSA	Boston Square Analysis
CAPEX	Capital Expenditure
CCUS	Carbon Capture Use and Storage
CED	Cumulative Energy Demand
CLSF	Carbon Sequestration Leadership Forum
DX.X, DXX	DeliverableX.X as numbered in Annex1; DeliverableXX as numbered by EC
DHF	Depleted Hydrocarbon Fields
DSA	Deep Saline Aquifer
EC	European Commission
EOR	Enhanced Oil Recovery
EU ETS	European Union Emission Trading System
FTE	Full Time Equivalent (Jobs)
GA	General Assembly
IC	Industry Club
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
MRIO	Multi-Regional Input Output
MSR	Market Stability Reserve
OPEX	Operational Expenditure
R&D	Research and Development
RSC	Regional Stakeholder Committee
SEF	Storage efficiency factor
SPE	Society of Petroleum Engineers
SRMS	Storage Ressources Management System
TEA	Techno-Economic Assessments
TERR	Techno-Economic Resource-Reserve

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TRL	Technology Readiness Leve
WP	Work Package

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