Developing CCUS in Mediterranean Region – Technical Evaluation of Promising Value Chains

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Abstract

Successfully developing multiple regional Carbon Capture, Utilization and Storage (CCUS) value chains to decarbonize industry and deliver negative emissions is of the highest urgency for the European Union to reach its climate change mitigation targets. Although about 40 CCS sites are operational worldwide, the development of this sector in Europe has been slow and concentrated around the North Sea. This paper explores the potential for enabling CCUS value chain deployment in the Mediterranean Sea region with lower maturity level for CCUS.

A screening has been carried out in Spain, France, Italy, Greece and Türkiye to map CO_2 emission sources, transport options, storage sites, and CO_2 utilization projects. The process led to the identification of four new promising national or cross-border CCUS value chains: (1) the Soma - İzmir Aliağa – Prinos value chain (Türkiye and Greece); (2) the Ebro offshore value chain (Spain and France); (3) the Beaucaire value chain (France) and (4) the Southern Italy value chain (Italy-Greece). A technical modelling is performed on each value chain that considers all the aspects of the chain: CO_2 emissions captured, CO_2 transport modes, pipelines design and specifications, intermediate storage, injection infrastructure, project duration, CO_2 use options and quantity. This paper presents detailed technical evaluation of the Spain-France CCUS value chain as a case study. Technical evaluation of these promising value chains paves the way for upcoming economic analysis and development of business models, leading to the emergence of new PCI in the Mediterranean region and the development of CCUS projects.

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Keywords: CCUS value chain; technical modelling; Mediterranean Sea; industrial cluster; CO_2 transport; CO_2 storage; CO_2 utilisation

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1. Introduction

Successfully developing multiple regional Carbon Capture, Utilization, and Storage (CCUS) value chains to decarbonize industry and deliver negative emissions is of the highest urgency for the European Union to reach its climate change mitigation targets. Although about 40 CCS sites are operational worldwide, the development of this sector in Europe has been slow and concentrated around the North Sea. This paper explores the potential for enabling CCUS value chain deployment in the Mediterranean Sea region with lower maturity level for CCUS.

A screening has been carried out in Spain, France, Italy, Greece and Türkiye to map industrial CO_2 emission sources, transport options, storage sites, and CO_2 utilization projects. The objective was to identify new potential value chains in addition to already ongoing projects. The process led to the definition of 4 new promising national or cross-border CCUS value chains: (1) the Soma - İzmir Aliağa – Prinos value chain (Türkiye and Greece); (2) the Southern Italy – Greece value chain; (3) the Beaucaire value chain (France); (4) the Ebro offshore value chain (Spain and France).

A technical modelling is performed considering all the aspects of the chain: CO_2 emissions captured, CO_2 transport modes, pipelines design and specifications, intermediate storage, injection infrastructure, project duration, CO_2 used options and quantity. The assessment was carried out with high level preliminary information publicly available and this should be confirmed and investigated in more details at a later stage. In a first part, this paper synthesizes the main technical features of each of the 4 Mediterranean value chains studied. Then, we present a detailed technical evaluation of the Spain-France CCUS value chain as a case study.

2. Method

2.1. High-level analysis and CCUS value chain definition

Based on a technical mapping of CO_2 emission sources, transport options and storage sites in countries around the Mediterranean Sea [1], promising emissions clusters have been identified, as well as potential storage options for the captured emissions. The total emissions volumes of the clusters and the storage capacities are taken into account. Transport options solutions are proposed, based on estimated distances, to connect the industrial cluster(s) with the potential storage site(s). This leads to the definition of several promising CCS value chains, in which potential for CO2 use was integrated [2].

2.2. Technical assessment of CCUS value chain

Inside identified industrial clusters, emitters where selected based on their location and emission volumes. Only potential emitters that release more than 100 kt CO_2 per year are considered. This threshold ensures that the focus remains on significant sources of emissions, where the impact of carbon capture technologies can be economically viable.

CO_2 emissions produced by emitters in 2021 are collected from the databases. Nevertheless, emissions for the Spain-France CCUS value chain were updated for 2022. However, in Türkiye there is no official public report available of industrial emissions, and emissions volumes for the selected industrial plants have been calculated using IPCC guidelines of 2006 [3], [1]. Information about the share of biogenic CO_2 in the total emissions produced by plants was also considered.

While CCUS is a promising technology for reducing CO_2 emissions, it may not be the only solution for all emitters. Some facilities may choose to decarbonize their operations through other means, such as electrification, fuel switching, process optimization, energy recovery, carbon offsetting etc. For this reason, CCUS contribution to each emitter carbon emissions reduction was estimated based on input from the International Energy Agency report [4] and current understanding of each industrial sector. Assumptions taken in the study are reported in Table 1.

Several technologies could be implemented depending on the specificities of the emitter (e.g. Post-Combustion Carbon Capture, Pre-Combustion Carbon Capture, Oxyfuel Processes). Despite the differences and challenges inherent to each technology, a typical effective carbon capture recovery is considered to be 95% for the case study.

The share of CO_2 captured to be used is considered as a range of values, at this early stage of analysis. The minimum corresponds to the amount of biogenic CO_2 that is captured in each cluster as biogenic CO_2 will be used in priority. The maximum corresponds to 30% of captured CO_2, based on the International Energy Report [5] and EU strategy [6] that considers that CO_2 utilization could be up to 30% of captured CO_2.

Table 1 Assumed share of captured CO_2 emissions depending on industry sector.

Facility Type	Assumed share of emissions addressed by CCUS [%]
Chemicals	35
Iron & Steel	25
Refineries	50
Power	50
Cement/Lime	65
Energy from waste	80
Hydrogen	85

The storage sites selected as part of the value chains are selected based on a screening carried out using existing public knowledge from previous research projects. Estimated storage capacity, as well as maturity of this evaluation, along with reservoir features, estimation of injectivity and of the number of injection wells, are information considered in the value chain assessment.

Transport of captured CO_2 between emitters and storage sites is defined, including local networks to collect CO_2 from the different emitters in each cluster, gathering hubs, and trunk transport to storage (shipping, offshore and onshore pipelines).

3. Mediterranean region CCUS Value Chains Description

3.1. Türkiye - Greece CCUS value chain

The Türkiye - Greece value chain includes two emission clusters, namely the Soma cluster and the İzmir Aliağa cluster in Türkiye, and an offshore storage site in Greece (Figure 1). The CO_2 emissions in Soma cluster are first transported to İzmir Aliağa via an onshore pipeline (120 km), then the total CO_2 emissions in both clusters are transported from İzmir Aliağa to Prinos storage site via a ship (360 km). The storage site considered for the Türkiye - Greece value chain is a deep saline aquifer in the Prinos Basin, which shows high CO2 storage capacity values (1Gt), but the maturity of the capacity estimates is low [1]. Still, such a scenario would allow sufficient capacity to store the high emissions of the Turkish clusters. Table 1 gives the key input parameters for the Türkiye - Greece value chain.

Table 1. Main features of the Türkiye - Greece value chain.

Cluster name	Number of emitters	Total CO_2 emissions (Mt/y)	Transport mode	Distance (km)	Storage site	Storage capacity (Mt)
Soma cluster	4	17.84	Onshore pipeline	149	Prinos Basin	1000
İzmir-Aliağa cluster	12	22.17	Onshore pipeline	20		
			Shipping	360		

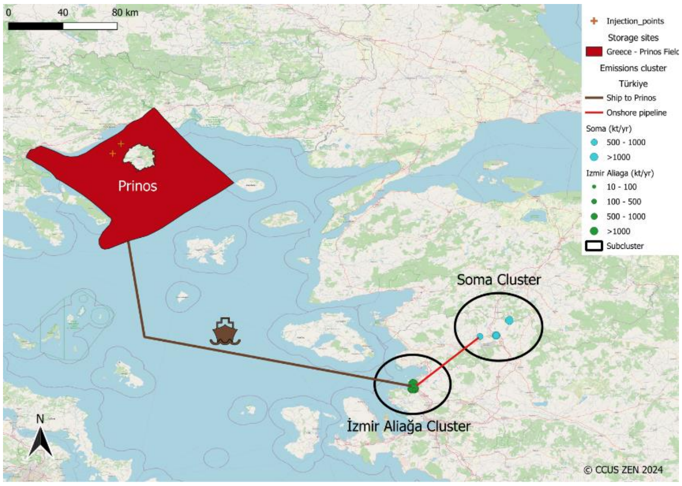

Figure 1. Türkiye - Greece value chain.

3.2. Spain-France value chain

The Spain-France value chain comprises three clusters of emitters and one storage site offshore in Spain that is yet to be developed: The Tarragona and the Barcelona clusters are two industrial clusters located in Spain, and the Fos-Marseille cluster is located in France (Figure 2). Emitters of the selected clusters are estimated to produce a total of 24 Mt/y of CO_2 (based on 2022 public emission data), part of which shall be reduced through the implementation of CCUS. The geological storage site is located offshore Tarragona in the Ebro Basin and is expected to store up to 200 Mt of CO_2. The Spain-France CO_2 value chain aims to balance the volume of captured emissions from promising clusters with the currently limited storage capacities. Based on this limited storage capacity and on the type of industries located in the clusters, a total volume of 9.77 Mt/y is estimated to be the design volume of the value chain (Table 3). However, it has been identified that the Lyon industrial cluster in France and emitters along the Rhone Valley could be integrated into the CCUS project if additional storage capacity is developed in the Ebro offshore area or if CO_2 volumes are directed to CO_2 utilisation units.

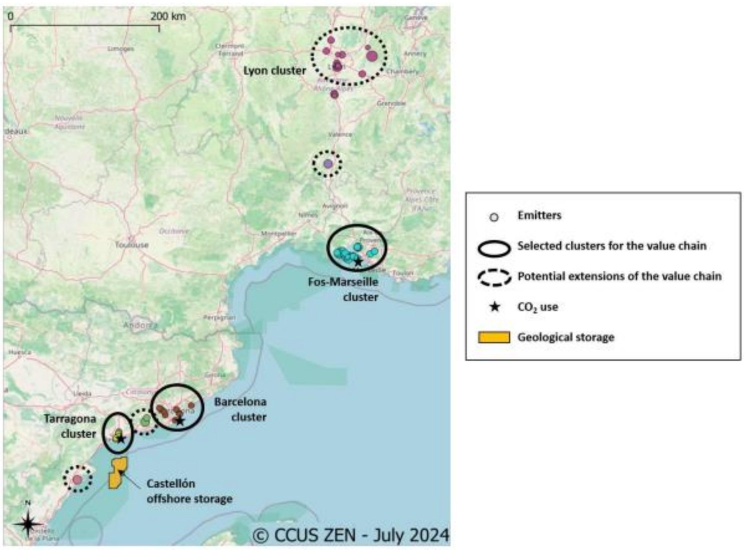

Figure 2 Spain-France CCUS Value Chain.

To facilitate the collection of CO_2 from various sources within each cluster, a local gathering network is planned prior to the CO_2 export. This network transports the CO_2 in its gaseous phase via pipelines that are specifically designed for this purpose. Once the CO_2 has been collected at each cluster level, two technical alternatives are considered for the Transportation System to the geological storage site (Reference Case and Alternative Case) (Figure 5). These will be described in more detail in the Case Study description in Section 4.

In the event of higher biogenic CO_2 emissions and availability of green hydrogen or renewable electricity at appropriate levels, emitters might want to consider the option of sending their CO_2 to the utilization plant to convert the CO_2 into a valuable product such as e-fuel. The scenario considers centralized CO_2 utilization plants located in the vicinity of the gathering station within each cluster.

3.3. Beaucaire value chain

The Beaucaire value chain is a local-scale scenario in Southern France involving two emitters close to Beaucaire and a storage site located about 30 km away (Figure 3). Two industrial sites are a paper plant and a cement plant, emitting 1.17 Mt/y in total, including 572 Mt from biomass. The storage option is onshore saline aquifer site Haut d'Albaron with storage capacity 34 Mt [7]. The emission sources and the storage site can be connected by an onshore pipeline of total length 32.6 (option 1) or 38.5 km (option 2), whether using direct route or, to some extent, existing gas pipeline corridors. Figure 3 locates emitters, storage and transport. Such a project would offer a local solution to reduce emissions of the two plants in Beaucaire for almost 30 years, with limited investments for transport infrastructures.

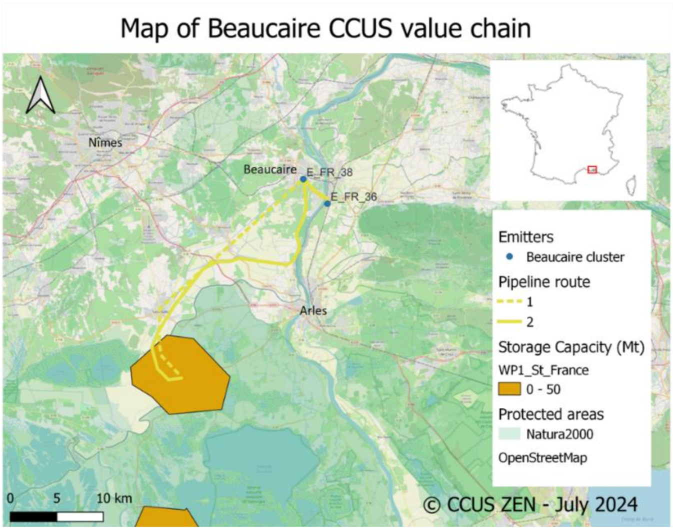

Figure 3 *Beaucaire value chain.*

3.4. The Italy – Greece value chain

The Italy – Greece case includes onshore pipelines in the southern part of Italy, from Priolo Gargallo in southwest, and from Brindisi in east. The onshore storage site Bradanica [8], is situated close to Taranto (Figure 4). It presents high capacity and good caprocks, with many potential emitters hubs within a short distance, using pipelines from nearby industry clusters. In addition to the pipeline system, we suggest ship transport from potentially France and Greece, with a harbour at Brindisi. Table 2 gives the key input parameters for the Italy – Greece value chain including transport and storage in southern Italy and ship transport from emission hubs around Athen in Greece.

Figure 4.Italy-Greece value chain.

Table 2. Main features of the Italy-Greece value chain.

Cluster name	Number of emitters	Total CO_2 emissions (Mt/y)	CO_2 captured (Mt/y)	Transport mode	Distance (km)	Storage site	Storage capacity (Mt)
Taranto cluster	7	12.41	5.00				
Brindisi cluster	4	6.89	3.37				
Priolo Garallo cluster	9	7.21	3.53	Onshore pipeline	513		
Messina cluster	3	3.82	1.91				
Catanzaro	1	1.35	0.67			Bradanica	344-1376
Agioi Theodoroi cluster	2	2.75	1.38				
Lavrion	1	1.39	0.70	Ship	900		
Athen cluster	5	5.28	2.78				
Total	32	41.09	19.30				

4. Case study – Technical evaluation of the Spain-France CCUS value chain

As previously described, the Spain-France value chain comprises three clusters of emitters and one storage site offshore in Spain. The technical definition of the value chain includes the assessment of the different blocks along the chain including capture, transport, utilization and storage systems.

This case study is a preliminary proposal for a potential CCUS network development within the region based on preliminary available information accessible to the authors to-date, subject to additional research and validation. However, it provides an initial framework for such a project which will require further engagements with all stakeholders to progress to the next phase.

4.1. Evaluation of CO_2 emission sources and captured volumes

The CO_2 volumes for the Spain-France value chain, specific to each cluster, are calculated using the three-step methodology presented in section 2.2. Based on these assumptions, the actual CO_2 volumes considered for the design of the value chain are presented in the following Table 3: Significant differences between clusters can be highlighted with Tarragona involving mainly refineries and chemicals plants, Barcelona having mainly power generation and cement plants and finally Fos-Marseille with a more diversified type of emitters such as power, refineries, chemical and iron & steel plants.

Table 3. CO_2 quantities per cluster considered for the Spain-France value chain

Country:	Cluster	Total 2022 CO_2 emissions (Mt/y)	Captured CO_2 emissions (Mt/y)	Captured biogenic CO_2 (Mt/y)	Number of Emitters
Spain	Tarragona Cluster	4.51	1.98	0.0007	5
	Barcelona Cluster	4.31	2.25	0.23	9
France	Fos-Marseille Cluster	14.99	5.54	0.21	18
Total:	-	23.82	9.77	0.44	32

4.2. Transportation schemes

As described in the previous table, the size of the Spain-France CO2 value chain Transport system is sized for a total injection rate of 9.77 Mt/y to ensure that emitters have a solution to manage their captured emissions. CO2 dehydration, conditioning, and treatment occurs at the emitter's site to meet the minimum specifications for pipeline and ship transportation.

Following a concept identification and screening workshop, two relevant transportation schemes have been defined and are described in the following paragraphs. Both cases consider the same emitters, onshore gathering network and storage site.

- The Reference Case considers an onshore gathering hub at Tarragona that collects the CO_2 from the three clusters: CO_2 from local Tarragona emitters, CO_2 from Barcelona sent by an offshore dense phase pipeline and CO_2 from Fos-Marseille transported by liquid CO_2 carriers (Figure 5a). From the onshore gathering hub in Tarragona, a single dense phase offshore pipeline sends the collected CO_2 to the subsea system, including subsea injection wells, around 60 km away from shore.
- The Alternative Case includes direct transport to the storage site from each cluster (Figure 5b). The offshore dense phase pipeline from Tarragona cluster only transports Tarragona emissions and sends the collected CO_2 from Tarragona to the subsea system, including subsea injection wells, around 60 km away. Captured CO_2 from Barcelona cluster are sent directly to the injection site by an offshore dense phase pipeline. Captured emissions from Fos-Marseille cluster are shipped directly to the offshore storage site. Their injection is done via a Floating Storage and Injection Unit (FSIU) and ties into the same subsea system.

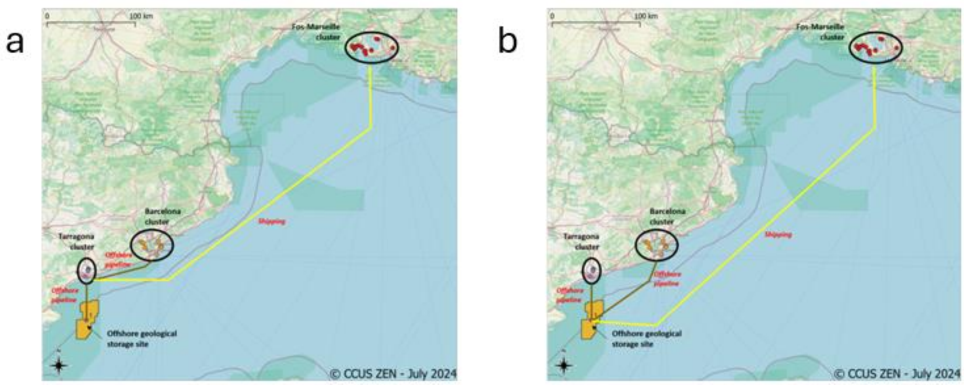

Figure 5. Transportation scenarios for Spain-France CO_2 value chain (a) Reference Case (b) Alternative Case

4.2.1. Reference Case Transportation System

CO_2 emissions are gathered in each cluster using a gas phase CO_2 gathering network. At each emitter plant, CO_2 is captured in a CO_2 capture unit, followed by a purification (dehydration) unit and compressed using a two-stage compressor. A sizing exercise has been performed to assess the compression and cooling duty required at each cluster.

Tarragona Cluster and Gathering Hub

- The Tarragona cluster comprises 5 emitters, collectively producing a total of 1.98 Mt/y of CO_2. This cluster features a gathering network that includes approximately 16 kilometers of onshore gas pipelines. CO_2 collected from this network is directed to a central compression facility located at the Tarragona Gathering Hub.
- Captured CO_2 coming from the three clusters is collected at Tarragona Gathering Hub, compressed (to reach the required injection pressure at the offshore site) and sent to one offshore dense phase pipeline. CO_2 received from Fos-Marseille is offloaded via loading arms at the terminal and stored in onshore buffer storage tanks (with a total volume of around 37,000 m^3). An export pump is needed to raise the pressure of the LCO_2 received from Fos-Marseille cluster via Shipping up to the required offshore pipeline inlet pressure. Barcelona emissions are expected to tie-in in Tarragona gathering facility, but no further compression is foreseen as the CO_2 will be compressed in Barcelona compression facility. A preliminary exercise was carried out to estimate the necessary injection pressure at the offshore injection site based on the reservoir characteristics. The estimated reservoir bottom hole pressure was found to be around 16 MPa leading to a pressure upstream the choke valve of 8.4 MPa. This led to the requirement of having the inlet pressure of the offshore injection pipeline in Tarragona to be 11.1 MPa and defined the sizing of the export compression facility.

The Table 4 below describes key design parameters of the Tarragona gathering hub and offshore injection pipeline.

Table 4. Tarragona Gathering Hub and Offshore Injection Pipeline (Reference Case)

Technical Parameter:	Value	Comment
Pipeline type	Dense Phase Pipeline	Inlet pipeline pressure of 11.1 MPa
Pipeline distance	60 km	Maximum water depth = 100 m
Pipeline Diameter	20 in	Outer Diameter
Export compression	8.2 MW	Two-stage compressor
Cooling duty	23.1 MW	Temperature to be below 40°C for the 1st stage and below 30°C for the 2nd stage
Export Pumping for stored LCO_2	2.2 MW	To raise the pressure of the LCO2 received from Fos-Marseille cluster via Shipping (compression from storage conditions (1.5 MPa) to 11.1MPa)
Heating Duty for stored LCO_2	26 MW	To raise the temperature from MP storage conditions (-33°C to approx. ambient temperature conditions)

Barcelona Cluster

- The Barcelona cluster consists of 8 emitters, which together produce a total of 2.25 Mt/y of CO_2. This cluster has a gathering network that includes approximately 49 km of onshore gas pipelines. The longer length of the pipelines in the Barcelona gathering network is necessary due to the more dispersed locations of the emitters within the cluster.
- CO_2 emissions from Barcelona Cluster are transported using an offshore dense phase pipeline from the Barcelona cluster to the inlet of the offshore dense phase pipeline located in the port of Tarragona. The inlet pressure of the pipeline in Barcelona was calculated at 12.5 MPa to ensure an arrival pressure at Tarragona gathering hub of 11.1MPa and then tie-in with Tarragona and Fos-Marseille emissions.

Key technical details are summarized in Table 5 below:

Table 5. CO_2 Transportation from Barcelona to Tarragona Injection Hub (Reference Case)

Technical Parameter:	Value	Comment
Pipeline type	Dense Phase Pipeline	Inlet pipeline pressure of 12.5MPa. Arrival pressure at Tarragona 11.1 MPa
Pipeline distance	106 km	Maximum water depth = 80m
Diameter	14 in	Outer Diameter
Export compression	10 MW	Two-stage compressor
Cooling Duty	27.4 MW	Temperature to be below 40°C for the 1st stage and below 30°C for the 2nd stage

<u>Fos-Marseille Cluster</u>

- The Fos-Marseille cluster consists of 18 emitters which together produce a total of 5.75 Mt of CO_2 per year. A preliminary assumption of 50 km of onshore pipeline has been made to gather emissions from the selected local emitters.
- Captured CO_2 from Fos-Marseille is liquefied and loaded on LCO_2 ships for its transportation to Tarragona Gathering Hub. LCO_2 ships operate at Medium Pressure conditions (i.e. 1.5-2.0 MPa and -15°C). A preliminary logistic study was performed to define the number of ships, onboard storage volumes and onshore storage volumes to ensure a continuous handling of the CO_2.

Main technical parameters of Fos-Marseille CO_2 Liquefaction and LCO_2 Export Terminal are presented in Table 6.

Table 6. CO_2 Transportation from Fos-Marseille Cluster to Tarragona Injection Hub (Reference Case)

Technical Parameter:	Value	Comment
Shipping distance	470 km	Approx distance from Fos-Marseille to Tarragona
Liquefaction Duty	12.7 MW / t CO_2	At Fos-Marseille port
LCO_2 ship capacity (gross)	32,600 m^3	MP conditions
Number of Ships	2	Travelling speed 12 knots
LCO_2 storage volume	43,200 m^3	Fos-Marseille onshore terminal buffer storage.
LCO_2 storage tanks	25 tanks in total at MP conditions	A volume of around 1730 m3 per tank is assumed.

4.2.2. Alternative Case Transportation System

This option considers the same emitters, onshore gathering network, storage site and number of injection wells. The difference with the Reference case is linked to the Transportation system, which considers two dedicated dense phase pipelines: one from Tarragona, and one from Barcelona, sending dense phase CO_2 to the subsea injection system and then storage reservoir.

<u>CO_2 Transportation from Tarragona to Subsea Injection System</u>

CO_2 captured from Tarragona emitters is conveyed to the injection site through an offshore dense phase pipeline. The transported flowrate is lower than the base case, amounting to 1,981 Mt/y. In this alternative scenario, no LCO2 is managed in Tarragona, as emissions from the Fos-Marseille Cluster are redirected to a Floating Storage and Injection Unit at the offshore storage site.

Table 7. CO_2 Transportation from Barcelona to Offshore injection site (Alternative Case)

Technical Parameter:	Value	Comment
Pipeline type	Dense phase pipeline	Inlet pipeline pressure of 11.4 MPa
Pipeline distance	60 km	Maximum water depth = 100m
Diameter	12 in	Outer Diameter
Export compression	8.3 MW	Two-stage compressor
Cooling duty	23.3 MW	Temperature to be below 40°C for the 1st stage and below 30°C for the 2nd stage

CO_2 Transportation from Barcelona to Subsea Injection System

CO_2 collected from Barcelona emitters is directed to the injection site via a 130km offshore dense phase pipeline. The transported volume corresponds solely to the emissions from the Barcelona cluster, totalling 2.25 Mt/y.

Table 8. CO_2 Transportation from Barcelona to Offshore injection site (Alternative Case)

Technical Parameter:	Value	Comment
Pipeline type	Dense phase pipeline	Inlet pipeline pressure of 13.0 MPa. Arrival pressure at offshore site (upstream choke) 8.4 MPa
Pipeline distance	130 km	Maximum water depth = 80m
Diameter	14 in	Outer Diameter
Export compression	10.2 MW	Two-stage compressor
Cooling duty	27.7 MW	Temperature to be below 40°C for the 1st stage and below 30°C for the 2nd stage

CO_2 Transportation from Fos-Marseille to Floating Storage and Injection Unit (FSIU)

Similarly to the Reference Case, CO_2 collected from Fos-Marseille emitters undergo liquefaction and is transported by LCO_2 ships. These ships deliver liquid CO_2 to a FSIU near the geological reservoir. The travel distance from Fos-Marseille to the FSIU location spans 470 km, with considerations for the same ship size and number as in the Reference case. The FSIU serves several key functions, including the continuous injection of CO_2 in a supercritical phase at specified pressure and temperature levels, storage of liquid CO_2 parcels and buffer volumes, offloading liquid CO_2 from LCO_2 ships in offshore conditions, and permanent mooring above the subsea injection wells. The facility, designed for MP conditions, boasts storage tanks totaling 38,800 m^3 for continuous CO_2 injection.

4.2.3. Comparison

Both cases are deemed technically feasible with the available information to-date. Further investigations are required to confirm, for example, emission volumes, pipeline routings, available footprint at the various clusters' location. The Reference case assumes an onshore gathering hub in Tarragona while the Alternative case considers a direct injection to the offshore injection site from each cluster. The Alternative case might be less impactful on the onshore sites but will require the development of a FSIU which has not yet been deployed at industrial scale. It could prove also to be more flexible as ships from other emitting locations could offload their CO_2 directly at the injection site. This opportunity will need to be further assessed with detailed logistics evaluation.

4.3. Storage

The storage site considered for the Spain-France value chain is an offshore storage site near Tarragona in the Ebro basin (Spain). This site is studied in the ongoing H2020 Pilot STRATEGY project [9][10]. The targeted reservoir is in the upper Miocene Castellón Sandstones, which runs from approximately 1600 m to 1900 m, overlain by the Ebro clays (Pliocene). Analysis of neighboring wells data predicted promising properties for reservoir and sealing. Seal thickness is extrapolated from well data (Salmonete-1 and Castellon B-13, source: https://info.igme.es/Hidrocarburos/). First estimations of the storage potential in the area indicate a capacity over 200 Mt based on communication received by Repsol Exploration for the injection site. The reservoir's parameters are summarized in Table 9. Number of injection wells is estimated to be 10, to inject up to 9.77 Mt/y. Many existing wells are registered in the Ebro offshore storage area. However, none of them could be considered for repurposing for CO_2 injection, nor crosses the targeted structure. The majority is plugged in and abandoned. Drilling new wells should be considered. Continuous injection of CO_2 in the reservoir is assumed with 20 years of storage and injection lifetime.

Table 9 Reservoir parameters for Castellón storage site

Storage site parameters	Units	Value	Storage site parameters	Units	Value
Country		Spain	Reservoir pressure @1600m	MPa	16
Site name		Castellón	Reservoir temperature @1600m	°C	74
Onshore / offshore		Offshore	Porosity	%	14-20
Reservoir Lithology		Upper Miocene Castellón Sandstone	Permeability	D	0.010-0.500
Top depth	m	1600	Average Storage Capacity	Mt	>200
Thickness	m	300-600	Cap rocks		Ebro Clays
			Seal thickness	m	900

4.4. Utilization

CO_2 utilization involves diverse technologies producing fuels, chemicals, and materials crucial for various sectors. While some technologies are ready for industrial use, others are in the early development stages. In the context of value chain development, CO_2 emitters must decide whether captured CO_2 will be stored permanently in geological reservoirs or utilized as feedstock in CO_2 utilization plants. The chosen preliminary scenario involves centralized CO_2 utilization plants near each cluster's gathering station, focusing on producing e-Methanol or e-SAF, aligned with European legislation and existing projects in France and Spain. Beyond energy applications, other applications could be for material applications, such as mineralization. Mineralization involves the permanent chemical binding of CO_2 into mineral-rich materials like calcium or magnesium-based carbonates but is not yet developed at large industrial scale.

In the current value chain, the amount of CO_2 directed to utilisation for producing e-fuels (potentially ranging from 4% to 30% in the case study) will be driven by several factors such as: technical maturity of the solution, availability of hydrogen and renewable energies, CO_2 nature (biogenic or fossil), etc. Although biogenic CO_2 share is currently minimal in the regions, it could rise if emitters shift to biomass-derived fuels. Biogenic CO_2 is anticipated to play a more significant role in CCU post-2041, especially in production of renewable fuels.

Conclusion and perspectives

Technical evaluation of the CCUS value chain paves the way for an economic assessment, which is the following step of this study. Costs estimation and development of business models will be key to foster to the development of

CCUS projects. There is a rising potential in the Mediterranean region with Prinos storage development in Greece, and TarraCO2 project in Spain, for which Repsol applied for a research permit and received grant from Innovation Fund. By defining and assessment of promising CCUS value chains in the Mediterranean region, this study encourages the emergence of new PCI in the region. Beyond technical evaluation, successful development of CCUS projects will requires integrating non-technical aspects, as legal, social, political frameworks will be paramount component of the value chain deployment.

Acknowledgements

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References

[1] Ringstad et al. (2023), Deliverable 1.1 High-level regional mapping of CO2 emission sources, utilization industry and infrastructure in the Baltic Sea and Mediterranean Sea regions. EU Horizon Europe CCUS ZEN. Project 101075693

[2] Gravaud, I., Shogenova, A., Shogenov, K., Sousa, L.H., Wójcicki, A., Lothe, A.E., Cruard, Q., Sınayuç, Ç., Yıldırım, B., Bulbul, S., Stevenson, R. & Perimenis, A. (2024). Deliverable 1.2 Identification of promising CCUS value chains in the two ZEN regions for further analyses in WP3. Open report in EU Horizon Europe CCUS ZEN. Project 101075693.

[3] IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K. (eds). Published: IGES, Japan.

[4] IEA (2019). International Energy Agency. Putting CO2 to Use, September 2019, Creating value from emissions

[5] IEA (2020). CCUS in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/ccus-in-clean-energy-transitions, Licence: CC BY 4.0

[6] EC (2024a). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Towards an ambitious Industrial Carbon Management for the EU, Retrieved online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX%3A52024DC0062

[7] Grataloup S., Coueffe R., Tourlière B., Le Thiez P. (2012) – Identification des sites potentiels de stockage de CO2 et première estimations des capacités. PROJET VASCO – Phase 5 : Stockage en aquifères salins - Tache 5.2. Rapport final. BRGM/RP-64302-FR, 63p

[8] Donda, F., Volpi, V., Persoglia, S., Parushev, D., 2011: CO2 storage potential of deep saline aquifers: The case of Italy. International Journal of Greenhouse Gas Control, 327-335.

[9] Fleury et al. 2023a. D2.6 Petrophysics Report of all Regions. PilotSTRATEGY deliverable. EU H2020 PilotSTRATEGY project 101022664

[10] Fleury et al. 2023b. D2.8 Report on Geomechanical results for the 3 areas. PilotSTRATEGY deliverable. EU H2020 PilotSTRATEGY project 101022664