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Project Acronym:

CTS

Project Title:

CO2 Transport and Storage directly from a ship: flexible and cost-effective solutions for European offshore storage

Project start date: 01.03.2024

Duration: 21 months

FINAL REPORT

EXTRAS

Contractor:

The National Research-Development Institute for Marine Geology and Geoecology - GeoEcoMar

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EXECUTIVE SUMMARY OF THE PROJECT

The CTS project conducted a feasibility assessment of the use of direct ship injection technology (NEMO solution) for geological storage of CO2 in the Romanian offshore sector of the Black Sea.

Main Results

The project confirms that direct ship injection is technically feasible and economically competitive in Romania's offshore conditions. It offers a flexible alternative to conventional infrastructure based on pipelines and ships and allows for faster development of geological storage sites, reducing dependence on fixed offshore platforms and complex injection systems. The analysis covered the entire CCS chain - from emissions capture in Calarasi, Constanta and Medgidia, to multimodal onshore transport, maritime transport and offshore geological storage.

The comparative technical-economic assessment of transport options — pipelines, conventional vessels and NEMO direct injection vessel — shows that although pipelines remain the cheapest option on a large scale, direct ship injection can significantly reduce CAPEX and OPEX for the offshore storage part, partially offsetting the higher operational costs of transport. In addition, direct ship injection offers superior operational flexibility, especially in the initial phases of CCS deployment or in situations of temporary unavailability of offshore infrastructure.

Impact

The most important impact of the project is the demonstration that direct ship injection can accelerate the launch of CCS projects in Romania, providing a fast and low-risk way to access offshore storage capacities before the development of extensive pipeline networks. This significantly increases Romania's chances of meeting NZIA's (Net Zero Industry Act) obligations and supporting the decarbonisation of heavy industry.

The project also strengthens Romania's potential to become a future regional storage hub for CO_2 in the Black Sea, thanks to the mobility of maritime solutions which can integrate cross-border CO_2 flows.

FORESEEN/FINISHED OBJECTIVES

For the CTS project, the Romanian contractor achieved all the objectives.

The main reached objective was to demonstrate the technical and economic applicability of the direct ship injection to demonstrate the potential of the Romanian industry for CTS by increasing the flexibility and versatility of the value chain for carbon capture and storage, reducing the costs on the storage side for a possible CO_2 storage in the Black Sea, the exclusive economic area of Romania. This is particularly important, especially for accelerating the implementation of CCS technology at the national level and to help ensure the storage quota of over 10 Mt assigned to oil and gas operators in the country under the NZIA (Net Zero Industry ACT) regulation.

In addition to the main objective, the following secondary objectives were also achieved:

- Designing and assessing the CCS value chain for Romania and comparing different offshore transport options, including direct ship injection;
- Developing criteria to identify the most suitable conditions along the CCS value chain for applying direct ship injection in offshore CO_2 storage projects;

- Establishing dialogue with stakeholders, in Romania in particular, in order to identify the challenges and factors leading to the adoption of CO_2 direct ship injection technology and to determine the weaknesses and strengths of the implementation of the technology;
- Contributions to the advancement towards piloting and demonstration of technology in Romania in line with the European CO_2 reduction targets and to allow CO_2 storage.

PRESENTATION OF THE RESULTS ACHIEVED, THE OUTCOME INDICATORS, THE NON-ACHIEVEMENTS RECORDED IN COMPARISON WITH THE ESTIMATED RESULTS WITHIN THE FUNDING APPLICATION (IF APPLICABLE) WITH THEIR JUSTIFICATION

A first important result of the project was the development of criteria to identify **the most suitable conditions along the CCS value chain for the application of direct ship injection.**

Within the value chain, several parameters apply to all actors, while others are specific to capture, transport or storage activities. Common parameters include regulations, environmental and social factors, CAPEX/OPEX, maturity level and overlap with other economic activities. Some criteria include both external and internal dimensions; for example, social acceptance is an external factor, while the way in which stakeholders value ESG is an internal factor. In the context of selection, no criterion should be considered universally prioritized, as each can become a critical bottleneck depending on local conditions. Even an optimal technical-economic case can become unviable if the regulatory regime is unfavorable or the social aspects are not managed.

Analyzing the criteria by components, the criteria for the capture component are:

- *Supply logistics*: 50 Km from a suitable port or the existence of a clear port connection; the navigation distance is subsequently took into account in optimisation.
- *CO_2 Value*, with preference for negative emission sources.
- *Future scenarios*, with a focus on long-term plans and the availability of CCS strategies.
- *Reliability and volume of supply*, which are not used as exclusion factors due to the flexibility offered by direct ship injection, especially for small emitters.

In areas with many potential emitters, a spider diagram can facilitate the preselection of actors to evaluate scenarios.

For *the storage component*, the criteria include:

- *Storage Readiness Level (SRL)*, preferably ≥ 3.
- *Storage Access*, rated by water depth, distance, existing infrastructure and preliminary costs.
- *Overlap with other economic activities*, such as maritime traffic or other offshore uses.
- *Other site-specific factors*, such as salinity and risks of gas hydrate formation.

Individual factors can be weighted and combined into a normalized score (0–1), allowing the representation of the four categories in a spider chart that is useful for comparing sites. The final

selection is then carried out in the framework of the scenario evaluation, taking into account storage costs, injection feasibility and correlation of the captured volumes with the storage capacity.

Based on the formulated criteria, the components of the CCS value chain for Romania were selected.

The most important result was the analysis of the Romanian carbon capture and storage value chain, which includes direct ship injection and comparison with conventional transport solutions.

The Romanian carbon capture and storage value chain for the implementation of the direct ship injection technology, hereinafter referred to as the Romanian scenario, was completed during 2025 and is illustrated in Figure 1.

The Romanian scenario involves capturing CO_2 from the industrial facilities in Călărași and Constanța (including Medgidia) and storing it in offshore solutions, potential aquifers and depleted hydrocarbon deposits in the Black Sea.

The Călărași industrial cluster considered includes 2 industrial plants, S.C. SILCOTUB S.A. (steel manufacturer) and S.C. SAINT-GOBAIN GLASS ROMANIA S.R.L. (glass manufacturer) emitting an amount of 149140 t CO_2 eq. in 2023.

For the Constanta cluster, 5 industrial plants were considered, the cement factory from Medgidia (ROMCIM S.A.), an energy production and heating installation from Constanta (S.C. Termocentrale Constanta S.R.L.), an energy production plant (Rompetrol Energy S.A. – the former Midia power plant), a refinery (S.C. Rompetrol Rafinare S.A. – Petromidia) and a lime plant (S.C. CELCO. The 5 industrial plants emitted a total of 2032535 t CO_2 eq. in 2023.

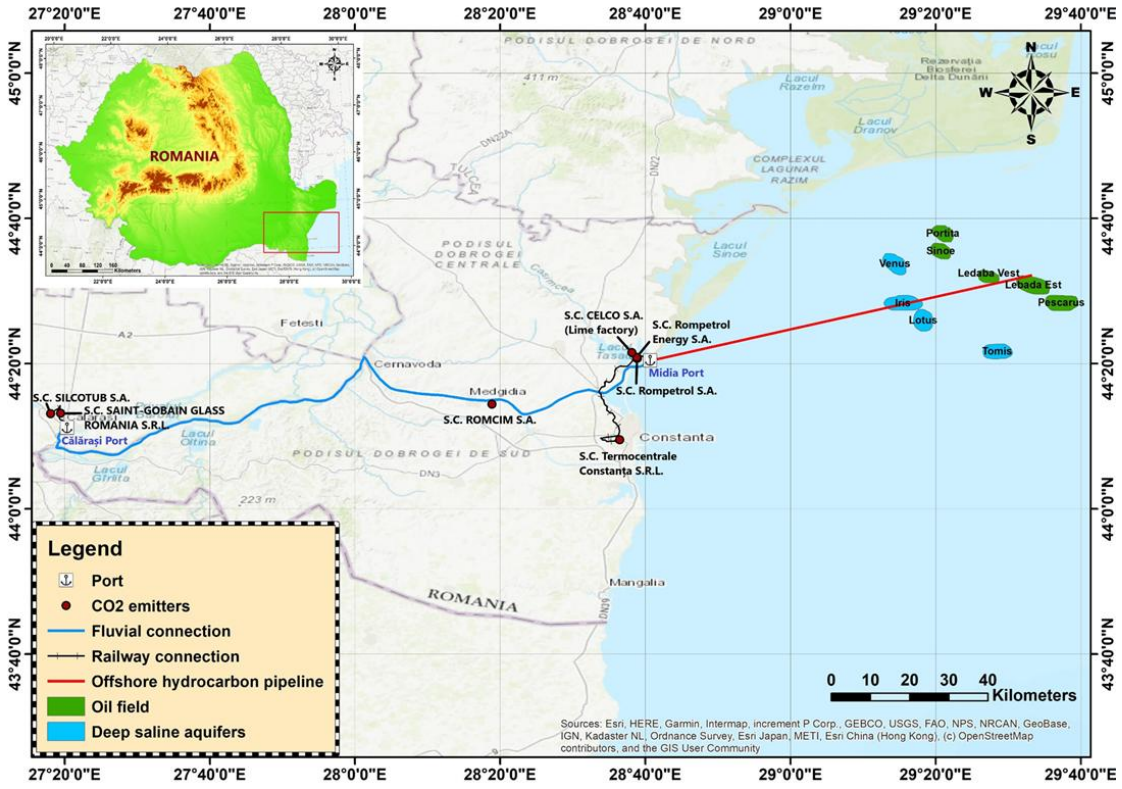

Figure 1. CCS value chain map for Romania

As storage solutions for CO_2 captured from the 2 industrial clusters, we selected 4 potential saline aquifers (Venus, Iris, Tomis, Lotus) and 3 hydrocarbon deposits (Lebada Est, Lebada Vest and Sinoe). All potential storage sites are in shallow waters and most have deep reservoirs (1800 – 2700 m), except for the Venus structure which has a 1000 m deep reservoir.

Based on the data collected for these potential storage sites, an estimate of the geological storage capacity has been made. The estimation of storage capacity for deep saline aquifers was made according to the methodology used in the EUGeoCapacity project (Vangkilde-Pedersen et al, 2009) resulting in a storage capacity of 108 Mt (Dudu et al., 2025).

Regarding the hydrocarbon deposits, the fields selected as potential storage sites have been exploited for more than 30 years, being discovered during the 1980s exploration campaign of the Black Sea, the exclusive economic area of Romania. The three fields are currently operated by OMV Petrom. The available public data is limited.

For these fields, the storage capacity calculation was made considering only oil reservoirs, data for gas reservoirs being considered insufficient. Due to the limited data available, we used a simple formula, also implemented within the EUGeoCapacity project (Vangkilde-Pedersen et al., 2009), resulting in a storage capacity of 59 Mt (Dudu et al, 2025).

In the CTS scenario, transport is conceived as multimodal, a combination of trains, river transport and maritime transport (via pipelines, conventional ships and direct ship injection). Depending on the transport in the maritime segment, three scenarios are distinguished, but the onshore transport component is common.

From the Midia hub three options were analyzed in the CTS project as scenarios for the Romanian case:

- Scenario 1: From the Midia hub, CO_2 will be transported through an offshore pipeline to a central platform from which CO_2 will be distributed to storage sites.
- Scenario 2: From the Midia hub, CO_2 will be loaded onto conventional vessels and transported to an offshore platform, from where it will be distributed to storage sites.
- Scenario 3: From the Midia hub, CO_2 will be loaded onto a specific direct injection vessel and injected directly into the selected offshore storage tanks.

The techno-economic analysis of the Romanian scenario within the CTS project was carried out using a tool initially developed within the STRATEGY CCUS project. This tool was slightly modified and updated for CTS.

For each scenario analyzed, investment and operational costs were calculated for all 3 components, capture, transport and storage, as well as the price per CO_2 captured, transported and stored.

The most expensive scenario, referring to the total costs, is the one involving offshore transport by conventional vessels. The cheapest scenario is the one involving transport through pipelines. Looking at transport costs, the costs are the highest for the NEMO scenario, but this scenario also offers significant reductions for storage operators at both CAPEX and OPEX levels. For the capture side, the costs are identical for all scenarios, the difference being recorded only in the transportation and storage side.

The direct ship injection technology (the NEMO solution) can be considered competitive in relation to conventional ship transport, with significant cost reductions on the storage side. In the case of this technology, transportation costs are slightly increased due to the need for investment (CAPEX)

in CO_2 reconditioning equipment (pumps and heaters) and CO_2 reconditioning on board in the operational phase (OPEX).

Although pipeline transport may seem much more cost-effective financially, the use of permanent, conventional infrastructure (pipelines, platforms) also comes with significant risks. In the event of an accident (e.g. compression failure, rupture or pipeline problem), CO_2 will have to be ventilated into the atmosphere. In the case of using direct ship injection, each vessel has handling and injection equipment, so the failure of a vessel or a single storage site only means the failure of part of the value chain, not the entire value chain.

After completing the analysis of the Romanian CCS value chain, synergies with the Ukrainian scenario were also analyzed in order to obtain an integrated scenario for the north-west of the Black Sea. One of the most important synergies is the possibility of cross-border storage. In special situations, CO_2 captured from one country can be stored across the border using direct ship injection, further reducing risks.

The analysis of the end-users involvement, the Romanian stakeholders, that has started from the establishment of a dialogue to identify the challenges and factors that lead to the adoption of the CO_2 direct ship injection technology, represents another result of the project.

This result was originally derived from stakeholder mapping. The main emitters involved in the scenario, pipeline operators, potential storage operators, OMV Petrom and Romgaz, as well as the CO_2 geological storage regulator, ANRMPSG, were identified as stakeholders.

The end-users of the project have been informed about the project and the technology of direct ship injection since 2024. The strategy of involving these stakeholders included organizing individual meetings, seminars associated with project meetings, but also a regional workshop dedicated to the completion of the Romanian scenario.

As result indicators, we must first mention the analysis of the Romanian carbon capture and storage value chain, which includes direct ship injection for offshore storage in the Black Sea, Romania's exclusive economic zone. Secondly, from the dissemination of the project results, the publication of a scientific paper (A.-C. Dudu et al., “CTS Project: CO2 transport and storage solutions in the Black Sea,” Advances in Carbon Capture Utilization and Storage, Vol. 3, No. 1, pp. 13–24, Jan. 2025, https://doi.org/10.21595/accus.2024.24736) and participation in the prestigious conferences and seminars in the field with posters and oral presentations related to the scenario of implementing the technology of direct ship injection in the Black Sea (CO2GeoNet Open Forum 2024, 2025; GHGT17, Baltic Carbon Forum 2024, 2025; EAGE GET 2025, Trondheim CCS Conference 2025, CC Capacity Building Workshop) have resulted.

THE ESTIMATED IMPACT OF THE RESULTS ACHIEVED, WITH AN UNDERLINEMENT OF THE MOST SIGNIFICANT RESULT ACHIEVED

The most significant result obtained by the CTS project was the demonstration of the feasibility of using direct ship injection (the NEMO solution) for geological storage of CO_2 in the Romanian offshore sector of the Black Sea. The conclusion of the project is that direct ship injection of CO_2, using NEMO technology, represents a practical, flexible and timely option for capitalizing on the offshore storage potential in the Romanian sector of the Black Sea. This result constitutes a major step in strengthening Romania's readiness for CCS, providing a realistic path to reduce implementation risks, accelerate the first offshore storage project, and gradually develop the national system.

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