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# Accelerating Low carboN Industrial Growth through CCUS

# Deliverable Nr. D5.5.1

# Identification of CCUS Pathways in Romania

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# Executive summary

The present report summarizes part of the work done so far within Task 5.5. Evaluating transport and storage routes in the Oltenia region, sub-tasks 5.5.1. Identification and description of possible CCUS pathways in the Oltenia region and 5.5.2. Assessment of possibilities to use captured $CO_2$ in the western Black Sea area.

8 major $CO_2$ sources have been identified within the industrial cluster of the Oltenia region, 5 from the energy industry, 2 from chemical industry and one from the non-iron metals industry. These emissions totalled for 2017 16.078.594 t. The largest $CO_2$ emissions which were registered and verified for 2017 were the four coal-fired power plants from Oltenia Energy Complex, SE Rovinari, SE Turceni, SE Isalnita and SE Craiova II. The chemical industry is represented by 2 sources, Oltchim and Ciech Soda Romania, formerly known as Uzinele Sodice Govora, manufacturer of soda ash, water glass, sodium silicate and soda derivatives. The only source from the metallurgic industry (non-iron metals) is represented by Alro (Slatina), the only producer of primary aluminum and aluminum alloys in Romania.

Two types of CCUS pathways have been identified starting from the aforementioned sources, an onshore solution and an offshore one. The onshore solution considers utilizing the captured $CO_2$ within the Oltenia development region and the offshore solution considers transporting captured $CO_2$ from the Oltenia region along the Danube for utilization in the Black Sea.

Within the onshore solution, for each of the $CO_2$ sources, suitable sinks have been identified in the form of oil reservoirs currently in the tertiary phase of exploitation that can be used for injection of captured $CO_2$ and storage during the enhanced oil recovery operations.

For SE Isalnita, the $CO_2$-EOR solution is Bradesti oil reservoir. For CET Govora, Oltchim and Ciech Soda Romania, the most suitable oil reservoirs are represented by Cazanesti and Babeni fields. The $CO_2$ captured from SE Rovinari can be used within the $CO_2$-EOR operations in the Balteni field. For SE Turceni, the most suitable $CO_2$-EOR reservoir is the Bibesti-Bulbuceni oil structure. The $CO_2$ captured from both SE Craiova II and Alro can be used for $CO_2$-EOR operations within the structure Samnic-Ghercesti-Malu Mare.

In order to define the offshore solution, the first step was to identify the ports along the Danube which have the necessary infrastructure to facilitate the transport of $CO_2$ by ship to the Black Sea. 17 ports have been identified, from which, 11 are only fluvial, 3 are fluvial-maritime and 3 maritime.

Within the Black Sea, the major structural unit that accommodates oil reservoirs and potential storage structures and the only structure investigated so far from the $CO_2$ storage perspective is the Histria Depression. The oil reservoirs that can be used for injection and utilization of captured $CO_2$ for EOR are: Lebada Vest and Lebada Est, Sinoe, Portita, Pescarus and Delta.

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# 1 Introduction

The present report summarizes part of the work done so far within Task 5.5. Evaluating $CO_2$ transport and storage routes in the Oltenia region, sub-tasks 5.5.1. Identification and description of possible CCUS pathways in the Oltenia region and 5.5.2. Assessment of possibilities to use captured $CO_2$ in the western Black Sea area.

The objectives of this work were:

- To identify major $CO_2$ sources in Oltenia region;
- To identify suitable oil structures for $CO_2$-EOR within close proximity of the sources;
- To analyse transport options from source to sink within the Oltenia region;
- To identify ports along the Danube that can be used in order to transport by ship the $CO_2$ captured from Oltenia sources to the Black Sea area;
- To select oil structures in the western Black Sea that can constitute suitable $CO_2$-EOR solutions.

The report has two main chapters, Chapter 2 and Chapter 3.
Chapter 2 presents the situation of major $CO_2$ emissions in Oltenia region.
Chapter 3 illustrates the onshore and offshore CCUS pathways identified for Oltenia region.

# 2 $CO_2$ sources in Oltenia region

For 2017, within the South-West development region, including the Oltenia province, the total verified $CO_2$ emissions were 16.078.594 t. As it can be seen from Figure 1 and Table 1, the largest $CO_2$ emitters are the power plants within the Oltenia Energy Complex (Rovinari, Turceni, Ișalnița, Craiova II) and CET Govora. The industry of non-iron metals is represented by a single source, while the chemical industry is represented by two sources.

Oltenia Energy Complex, the company holding the four power plants is a major electricity producer, delivering around 25 % from the total electric energy of the country (ANRE, 2016).

SE Rovinari was put into operation between 1972 and 1978, it has three blocks of 330 MW, operating on lignite fuel. Two blocks are being upgraded and one block is being modernized. It is the largest source of $CO_2$ emissions in the country.

SE Turceni, according to the data published on the site Oltenia Energy Complex, was put into operation between 1978 and 1987 and has 4 blocks of 330 MW each, operating on lignite fuel, of which 2 are modernized and one is in progress of modernization

SE Ișalnița, according to the same source, was put into operation between 1964 and 1968 and has 2 partially modernized blocks of 315 MW each, operating on lignite fuel.

SE Craiova II was commissioned in 1987 and has two 150 MW blocks operating on lignite.

As a measure for reducing air pollution, all the energy blocks have been equipped with dense slurry and desulphurisation installations.

SE Craiova II is also the main source of the thermal energy supply system for the city of Craiova, through two cogeneration groups (on coal with gas, 2 × 150/120 MW), two hot water boilers (on coal with fuel, 2X100 Gcal / h), a boiler of 50 Gcal / h and a boiler of 30 Gcal / h.

CET Govora was put into operation in 1959 and represents an important producer and distributor of electricity and heat.

Alro Slatina was founded in 1961 and is currently the only producer of primary aluminum and aluminum alloys in Romania and the largest producer of aluminum in Central and Eastern Europe (except Russia). The aluminum production capacities are located in Slatina and include an electrolysis section, processing capabilities, including a foundry, hot and cold mills and an extrudate section. As an environmental protection measure, Alro has adopted the replacement of the fluoride-containing wet gas cleaning technology with the dry gas treatment technology (retention efficiency increased from 65% to over 99%) and has reduced the greenhouse gas emissions a few dozen times compared to 1989.

CIECH Soda Romania (formerly: Uzinele Sodice Govora) is located in southern Romania, in Govora. CIECH Soda Romania manufactures soda ash, water glass, sodium silicate and soda derivatives.

OLTCHIM is a major producer in the chemical industry in Central and Eastern Europe. OLTCHIM was founded in 1966 as the Chemical Works and since 1990 the company has operated as a joint stock company. OLTCHIM became a public company in 1997 by listing on the Bucharest Stock Exchange.

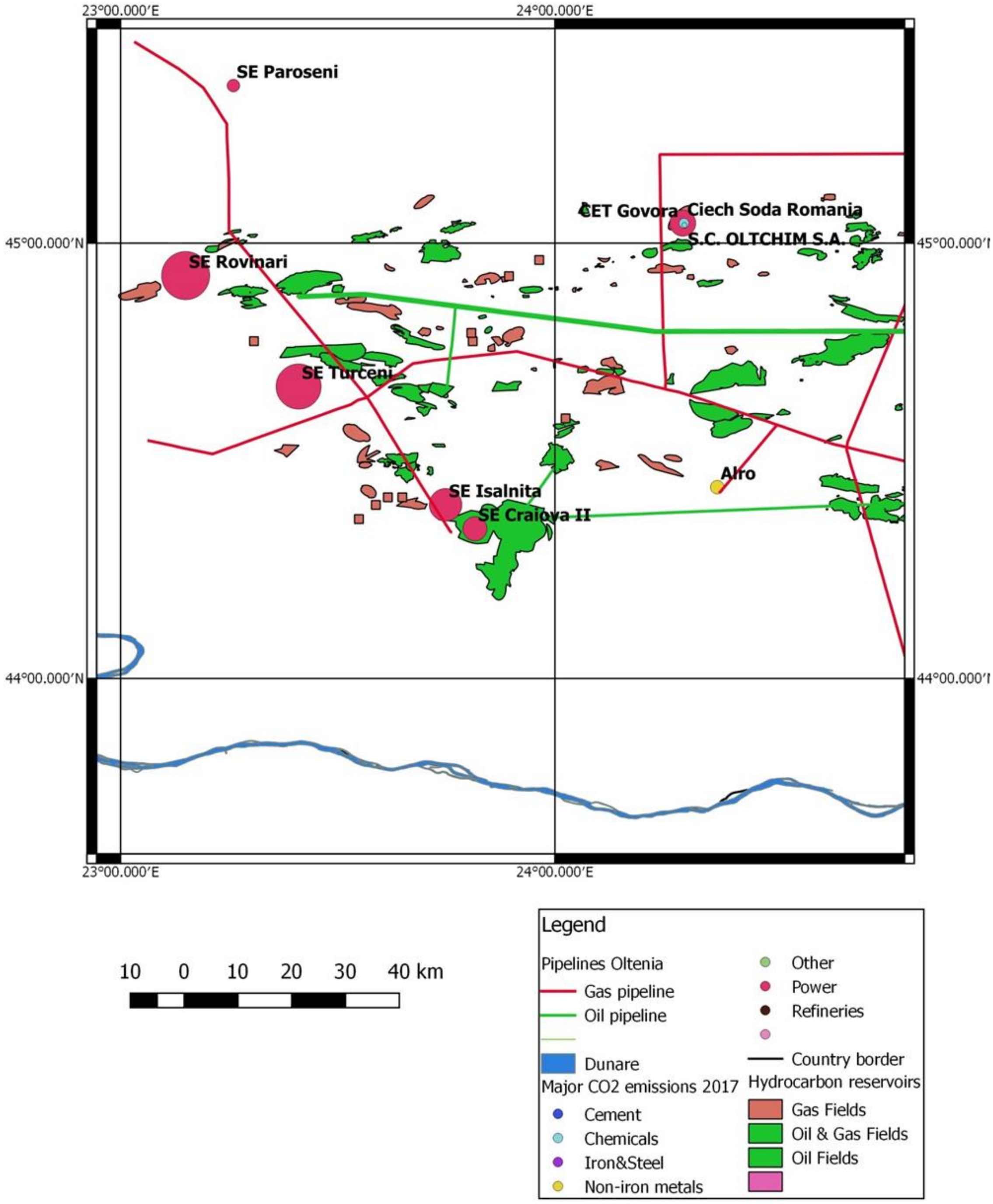


**Figure 1. GIS map showing the distribution of major $CO_2$ emission sources and oil and gas structures from the Oltenia region**

**Table 1. List of the major $CO_2$ emission from Oltenia region verified for 2014 and 2017**

| Name of the source | Emissions 2014 (t $CO_2$) | Emissions 2017 (t $CO_2$) | Technology |
|---|---|---|---|
| SE Rovinari | 4.469.942 | 5.782.942 | Energy |
| SE Turceni | 4.476.006 | 4.429.457 | Energy |
| SE Isalnita | 2.378.893 | 2.357.658 | Energy |
| CET Govora | 1.178.473 | 1.513.139 | Energy |
| SE Craiova II | 1.164.735 | 1.290.216 | Energy |
| Alro | 377.880 | 395.216 | Non-iron metals |
| Ciech Soda Romania - | 182.137 | 213.247 | Chemical industry |
| S.C. OLTCHIM S.A. | | 96.719 | Chemical industry |

# 3 Identification of CCUS pathways for Oltenia region

## 3.1 Onshore solutions

For every major $CO_2$ source, we have made a selection of the onshore oil fields that in their tertiary phase of exploitation might be available for the injection of $CO_2$ captured for enhanced oil recovery. The CCUS pathways obtained following this exercise is shown in Table 2. The selected reservoirs are also indicated in Figure 2.

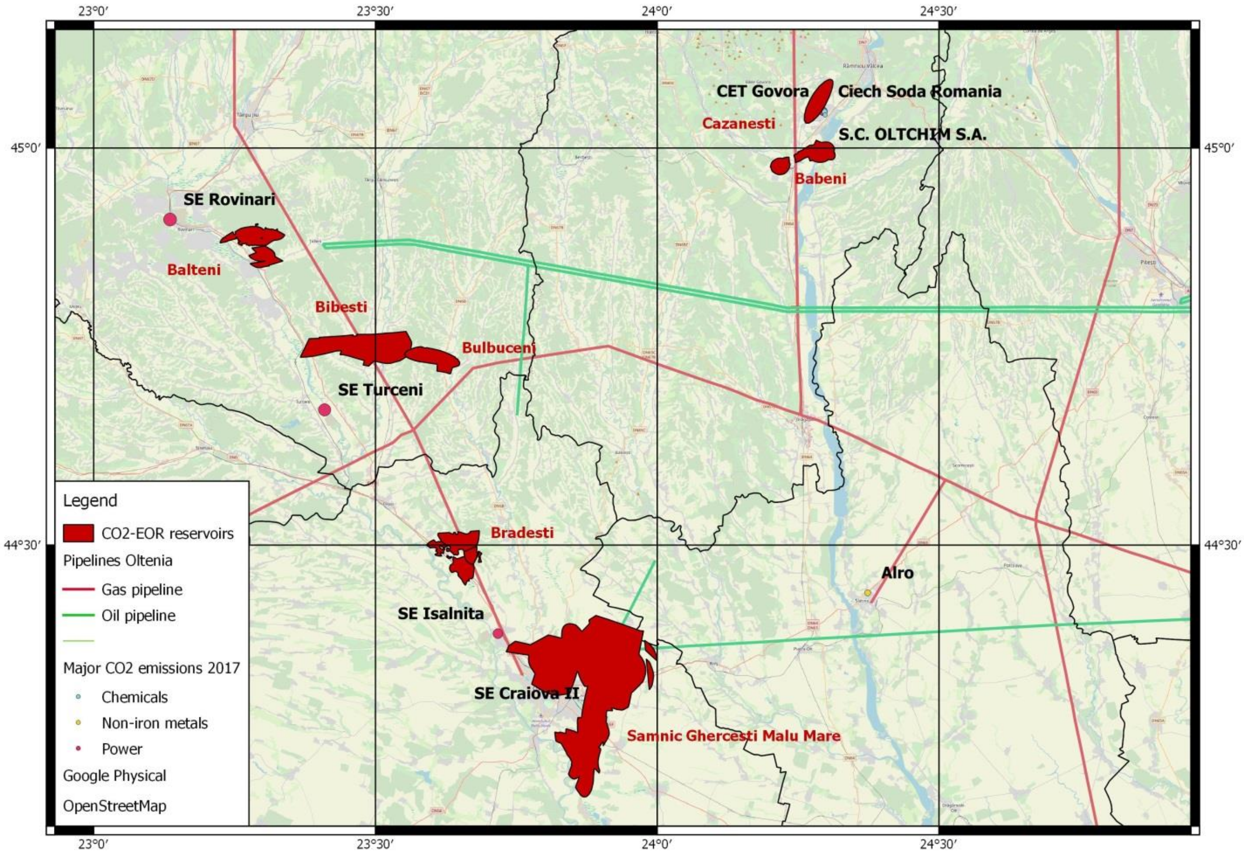


**Figure 2. Map showing the location of the $CO_2$ emission sources, selected $CO_2$-EOR reservoirs, existing pipelines in Oltenia region**

**Table 2. CCUS pathways in Oltenia region**

| $CO_2$ Source | Transport route | Oil Field | Distance (km) |
|---|---|---|---|
| SE Isalnita | Road, rail, pipeline | Bradesti | 12 |
| CET Govora, Oltchim, Ciech Soda Romania | Road, rail, pipeline | Cazanesti | 2 |
| CET Govora, Oltchim, Ciech Soda Romania | Road, rail, pipeline | Babeni | 6 |
| SE Rovinari | Road, rail, pipeline | Balteni | 13 |
| SE Turceni | Road, rail, pipeline | Bibesti-Bulbuceni | 12 |
| SE Craiova II | Road, rail, pipeline | Samnic, Ghercesti | 10 |
| Alro | Road, rail, pipeline | Samnic, Ghercesti | 38 |

The structure of Brădeşti geologically belongs to the Moesic Platform. It is located near the town of Craiova, being the most important field in close proximity to the Isalniţa power plant. Research on the field started in the year 1936 and continued until 1956, when important accumulations of hydrocarbons were recorded in the Triassic collectors, at depths of over 2000 m. The deepest wells drilled on this structure have encountered formations since Pre-Triassic age.
The structure of Brădeşti comprises 3 productive layers saturated with non-paraffinous oil and dissolved gas, namely Triassic, Dogger, and Sarmatian. The reservoirs of this structure are of a massive type, being mainly composed of limestones and limy sandstones. The reservoir water is of $CaCl_2$ type with a salinity of 3.20-8.60 mg/l and the dissolved gas contains 83-91% methane and 4-17% ethane. The Triassic porosity from Brădeşti field has a maximum value of 28%.

The Căzăneşti structure is located on the south side of the Govora-Ocnele Mari anticline. It is developed as a faulted monocline. Three wells of low depth were drilled here, which had gas at the gritty levels of the upper Tortonian. The flows showed a downward trend, proving the non-economic nature of the accumulation.

The Băbeni field, located in the eastern part of the Getic depression, is part of the structural alignment, composed of Colibaşi, Merişani, Săpunari and Grădiştea anticlines. The area is fragmented into many tectonic blocks, often hydrodynamically separated.
The accumulations of hydrocarbons are cantoned at the level of the Helvetian which is composed of two main lithostratigraphic units, as follows:
- Lower and intermediary Helvetian saturated with oil and primary gas cap;
- Upper Helvetian saturated only with gas.

The structure of Bâlteni from a geological point of view, is located in the western sector of the Getic Depression, about 26 km south of Târgu Jiu city, on the territory of Gorj County, near the $CO_2$ emissions of the Rovinari power plant. The exploitation of the Bâlteni field started in 1952. Oil accumulations were discovered in the Helvetian, Sarmatian and Meotian formations, as follows:

- Helvetian - oil reservoirs with dissolved associated gas and oil reservoirs with gas dome. It has a thickness of about 1000 m and is composed of intercalations of gry-green sands, gray sandstones, limestones and gray-green sandy marls;
- Sarmatian - oil reservoirs with dissolved associated gas, free gas and oil reservoirs with gas cap. It has a thickness of about 250 m in the apex area and 550 m on the flanks. The dips of the layers have values between 3° and 20°. It consists of thick banks of sands, loamy-gritty bundles separated by marly or marly-limestone intercalations.
- Meotian - oil reservoirs with dissolved associated gas and free gas reservoirs. The Meotian was divided into upper and lower - the upper part is predominantly pelitic, and at the bottom there are alternations of sands and sandstones. Its thickness is about 350 - 450 m, and the dips of the layers are of 4-5°.

The reservoirs of oil with associated gas are of layered type with edge water or massive with tabular water, tectonically and stratigraphically shielded. The oil accumulated in the Bâlteni reservoirs belongs to paraffin C class. The associated gas consists mainly of methane (88% vol - 95% vol). The waters of the three geological formations are $CaCl_2$ type chloride group, sodium subgroup.

The Bibeşti-Bulbuceni structure is located on the northern edge of the Moesian platform, at the contact with the Getic depression.

The seismic prospections from the period of 1962-1973, highlighted accumulations of hydrocarbons, contained in: Devonian, Triassic, Sarmatian and Meotian.

The Devonian is saturated with oil and dissolved associated gas. The highest depth where oil has been found is 4872 m. The Devonian is predominantly composed of dolomites with average porosity of 10%, being affected by fissures and cavities. The average saturation in interstitial water is about 40%, and the volume reduction factor is 2.2. The oil is of paraffin type with a density of 0.855 $kgf/dm^2$.

The Triassic is saturated with oil and dissolved associated gas, having very low permeabilities and porosities between 3.5-8.5%. The oil is of A2 type and has a density of 0.821-0.865 $kgf/dm^2$.

The Sarmatian is composed in the lower complexes of oil and dissolved associated gas, in the upper complexes having free gas. The thickness of the productive complexes ranges between 24-130 m each, with porosities between 2.3-24% and the water saturation is 35-53%. The oil density is 0.859-0.807 $kgf/dm^2$.

The Meotian is exclusively saturated with free gas, with porosity values of 18%, permeabilities between 5-100 mD and saturation in interstitial water of 40%.

Sâmnic and Ghercești structures are located near the town of Craiova. The Dogger proved to be saturated with oil, dissolved associated gas and gas from the gas cap. The development of the productive formation is reduced being divided into many tectonic blocks separated by watertight faults, with porosity and permeability variations, which have determined that these reservoirs to have an ordinary behaviour.

Also, saturated with free gas, on these structures is the Ponţian sandy complex, at depths of 230-350 m and is composed of sands, with rare and thin interlayers of sandstones and marls. The effective thickness of the sands varies between 2 and 30 m, the average porosity is about 34%, the permeability of about 230 mD, and the saturation in interstitial water is about 25%.
The gas is residue type with methane content of 97.85%, 0.04% ethane, 0.01% propane, and the rest being carbon dioxide and nitrogen.

## 3.2 Offshore solutions

Apart from the local, onshore transport, utilisation and storage solutions, there is also the possibility to capture the $CO_2$ from Oltenia cluster and to use it for $CO_2$-EOR operations in the western Black Sea Basin. Taking into account the large distances between the sources and the offshore sinks, the most feasible way to use the offshore would be to implement a multi-modal transport solution. This means that the $CO_2$ captured from Oltenia sources has to be transported by rail, road and/or pipeline to the closest Danube port equipped with an appropriate buffer. From this fluvial buffer, the $CO_2$ should be loaded on specialized ships/barges in order to be transferred along Danube river and Danube-Black Sea channel to the specialized marine buffer installed in Agigea port. From Agigea port there are two options to transport $CO_2$ to the offshore sinks: by pipeline or by specialized marine vessels. In this way, $CO_2$ storage operations including EOR or EGR could be developped in the western Black Sea Basin in a similar way with the North Sea.
The ports that have been identified as being of interest for the application of multi-modal transport in the CCUS method are presented in the figure and the table below.


**Figure 3. Map illustrating the ports on the Danube river**

**Table 3. Romanian ports of interest for application of multimodal transport of $CO_2$ in Romania**

| No | Port | Type port | Year of construction | Length of the docks |
|---|---|---|---|---|
| 1 | Orşova | fluvial | 1972 | 100 m |
| 2 | Drobeta-Turnu Severin | fluvial | 1972 | 939 m |
| 3 | Calafat | fluvial | 1830-1833 | 700 m |
| 4 | Bechet | fluvial | XIX century | 670 m |
| 5 | Corabia | fluvial | 1859/1866 | 1470 m |
| 6 | Turnu Măgurele | fluvial | 1883-1900 | 830 m |
| 7 | Zimnicea | fluvial | 1890-1900 | 600 m |
| 8 | Giurgiu | fluvial | 1896-1900 | 1750 m |
| 9 | Olteniţa | fluvial | after 1900 | 750 m |
| 10 | Călăraşi | fluvial | after 1900 | 620 m |
| 11 | Cernavodă | fluvial | 1975-1985 | 1180 m |
| 12 | Brăila | fluvial-maritime | 1836 | 5000 m |

| | | | | |
|---|---|---|---|---|
| 13 | Galaţi | fluvial-maritime | 1884 (multiple further developments) | 4840 m |
| 14 | Tulcea | fluvial-maritime | 1908 | 1900 m |
| 15 | Midia | maritime | 1949-1950 | 1415 m |
| 16 | Constanţa | maritime | 1857-1860 (multiple further developments) | 29000 m |
| 17 | Medgidia | maritime | 1975-1984 | 3000 m |

At the current knowledge level, the most favourable region for $CO_2$ geological storage is the Histria Depression. This depression comprises five hydrocarbon fields (discovered so far) located on a NW-SE alignment on its northern flank. These fields are:

- Lebada East, discovered in 1980, with oil in Albian and Upper Cretaceous rocks and gases in Eocene deposits;
- Lebada West, discovered in 1984, with oil in Albian, Upper Cretaceous and Eocene reservoirs;
- Sinoe, discovered in 1988, with oil in Albian reservoirs;
- Delta, discovered in 2007, with oil in Albian reservoirs;
- Pescarus, discovered in 1999, with oil in Upper Cretaceous (Cenomanian) reservoir.

The location of the fields can be seen in Figure 6. From these fields, only Lebada East and Lebada West can be used for $CO_2$-EOR operations and $CO_2$ storage purposes. These fields already have injection wells which are used for enhanced recovery operations (not involving $CO_2$).

**The East Lebada deposit** - was discovered in 1980, following the development and exploitation of the associated oil and gas deposit between July 1984 and January 1991, on three production platforms. Initially, the deposit started to produce in May 1987, in its eastern part, in natural mode. Secondary exploitation by water injection began after about 2 months. There are 3 defined deposits, superimposed vertically, cantained in Albian, Upper Cretaceous and Eocene reservoirs. In the oil field, of Albian age, East Lebada, two porous-permeable zones were divided, separated by two compact zones. The productive area comprises only the upper porous-permeable range.
The structural map at the Albian cap shows the shape of the trap, the water / oil and oil / gas boundaries, as well as the arrangement of the oil and gas wells, as well as the injection wells (Figure 4).

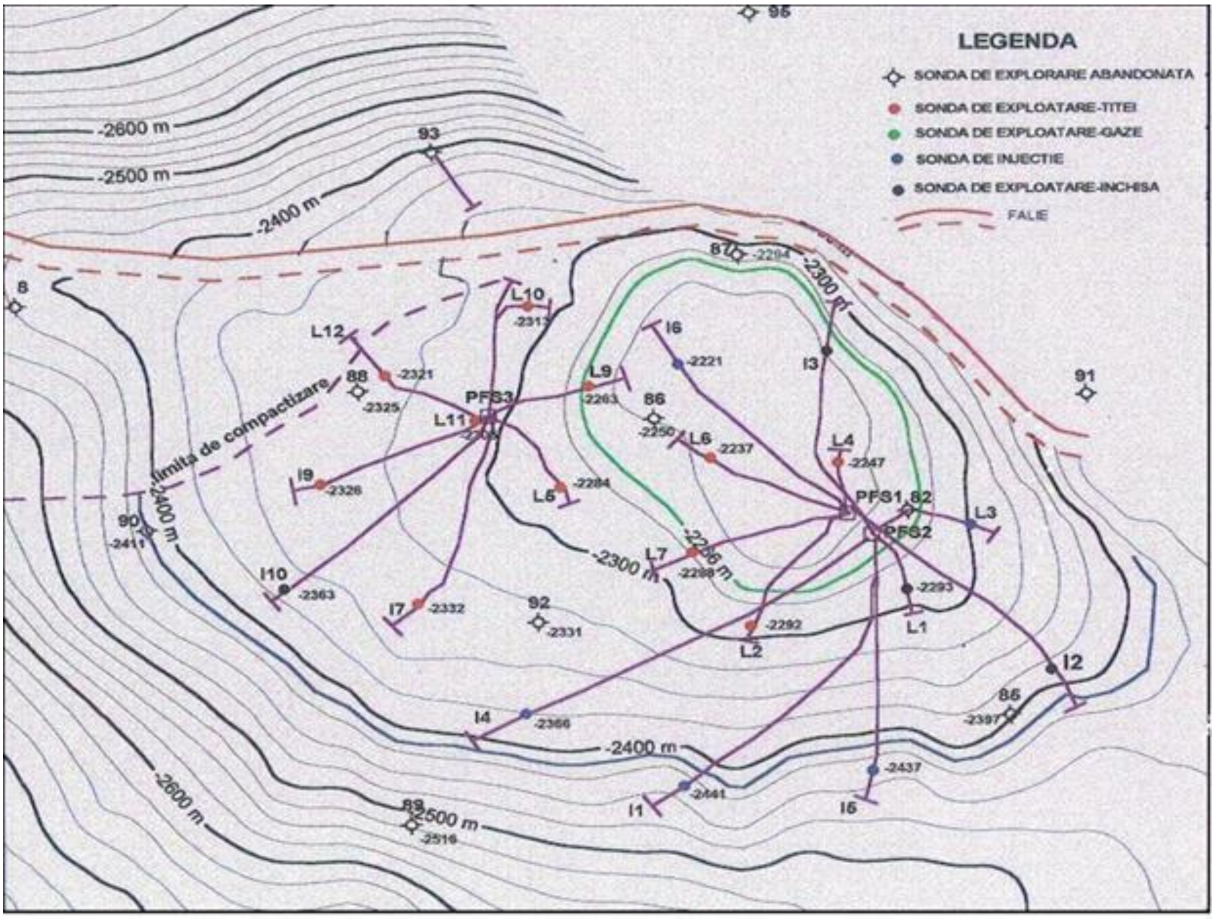


**Figure 4. Structural map at the Albian cap on the East Lebăda structure (after Ionescu G. et al, 2002).**

***The Upper Cretaceous deposit,*** quarried in fissured sandstone, with low permeability, developed through horizontal wells that defined a structural (anticlinal) trap with W-E orientation. The caprock consists of compact, Campanian limestone.

***The Eocene gas deposit,*** developed by a drilling program that comprised 9 wells with high inclinations (maximum 60 °), dirrectioanal drilling, originating from Line 4 (L4, Figure 4), is enclosed in a reservoir made of clay, micritic limestone and greasy limestone, with a thickness of 65 - 150 m.

The closest surface trap, in the East Lebada area, is the Eocene gas trap. The Eocene trap is controlled by a gradual reduction in lateral and vertical porosity. The screen consists of oligocene clays and a stratigraphic element, a permeability barrier that outlines the trap.

***West Lebăda deposit -*** was discovered in 1984 with the 82 Lebada West Probe that produced oil and associated gases from two Albian collectors. The drilling program comprised 9 production wells and 2 injection wells, production starting in April 1993. During the operation, it was found that apart from the two A3 and A4 collectors belonging to Albian, there is another dated collector on top of them. Vraconian, a distinct hydrodynamic unit, is characterized as a narrow-band gas field of crude oil.

Within the Albian formation four porous-permeable intervals were separated, characterized by different porosity values. The A3 and A4 layers, the productive ones, are located in the upper part of the Albian and have medium to good porosity and permeability values.

The ranges noted A1 and A2 are located in the lower part of the Albian and have very low porosities and permeabilities. The mechanism of the trap is complex with both structural and stratigraphic components. A combination of factors acts in the formation of the A4 layer trap, namely: an erosional truncation to the west, a tapering to the north, structural to the east, and facies compaction to the south. The screens of layers A3 and A4 consist of compacted areas of carbonate tiles interspersed with marl.

The structural form of the deposit is a corrugated monocline (Figure 5).

On the structure of Lebada Vest (West) deposit, a crude oil field was identified with primary gas head, enclosed in Eocene detritus rocks. The Eocene reservoir contains two porous-permeable layers E3, E4, with average and good porosity respectively. The closure of the E4 layer trap is made by erosion and erosion truncation in the east and by compaction in the west. The closure of the E3 trap is achieved by erosion and erosion truncation in the east and north and by structural closure and facies change in the west and south. The screen of the two layers E4 and E3 is represented by the Oligocene clays.

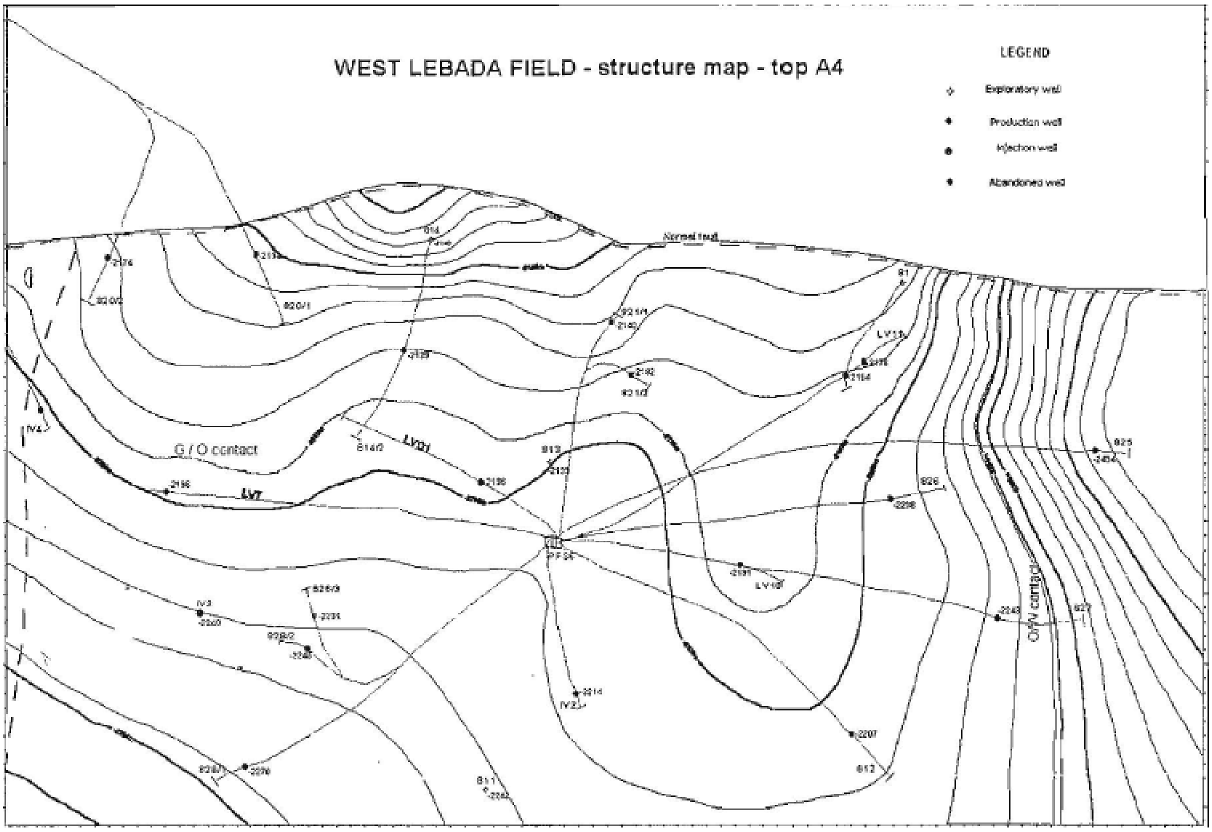


**Figure 5. Structural map at the top A4- Albian, on the structure Lebăda West (Ionescu G. et al, 2002)**

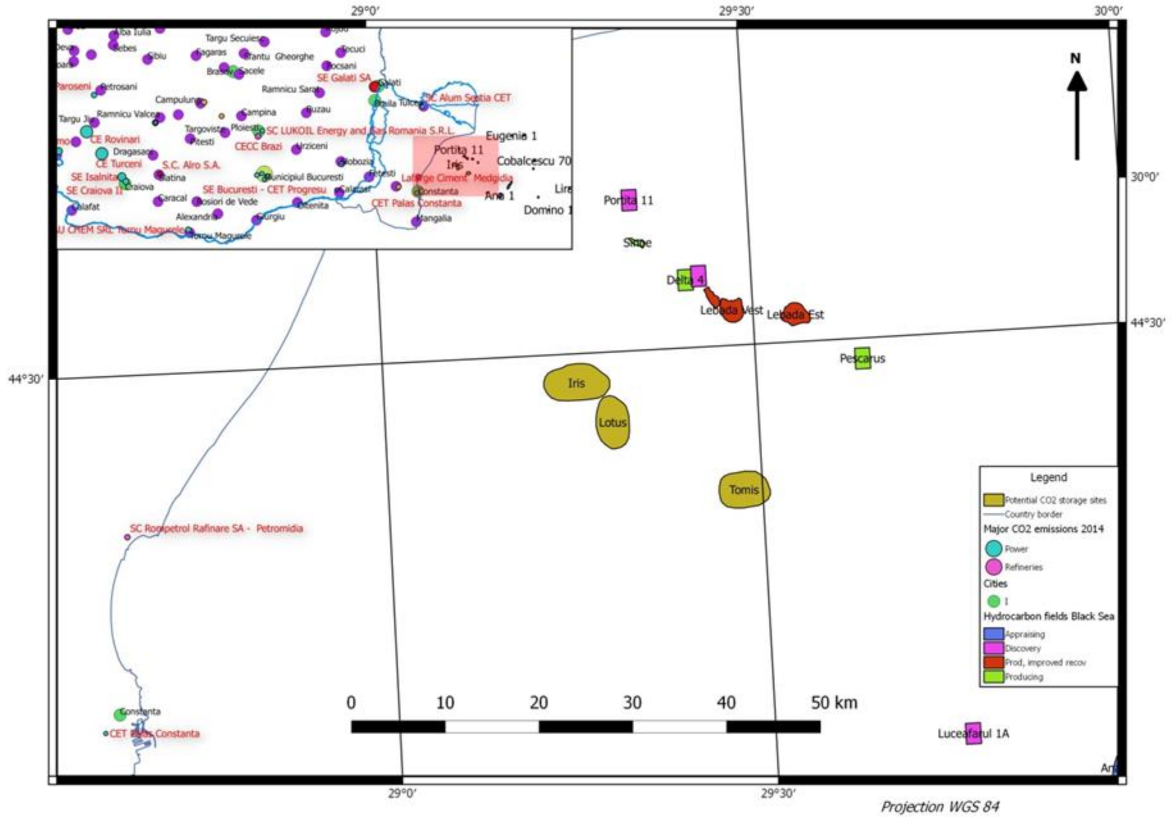


**Figure 6. Map illustrating the storage and utilisation (EOR) possibilities in Histria Depression (Black Sea)**

# 4 Conclusions

There are 8 major $CO_2$ sources within the industrial cluster of the Oltenia region, 5 from the energy industry, 2 from chemical industry and one from the non-iron metals industry. The largest $CO_2$ emissions which were registered and verified for 2017 for the four coal-fired power plants from the Oltenia Energy Complex, SE Rovinari, SE Turceni, SE Isalnita and SE Craiova II.

Two types of CCUS pathways have been identified starting from the aforementioned sources, an onshore solution and an offshore one. The onshore solution considers utilizing the captured $CO_2$ within Oltenia development region and the offshore solution considers transporting captured $CO_2$ from Oltenia region for utilization in the Black Sea.

Within the onshore solution, for each of the $CO_2$ sources, suitable sinks have been identified in the form of oil reservoirs currently in the tertiary phase of exploitation that can be used for injection of captured $CO_2$ and storage during enhanced oil recovery operations.

For SE Isalnita, the $CO_2$-EOR solution is Bradesti oil reservoir. For CET Govora, Oltchim and Ciech Soda Romania, the most suitable oil reservoirs are represented by Cazanesti and Babeni fields. The $CO_2$ captured from SE Rovinari can be used within $CO_2$-EOR operations in the Balteni field. For SE Turceni, the most suitable $CO_2$-EOR reservoir is the Bibesti-Bulbuceni oil structure. The $CO_2$ captured from both SE Craiova II and Alro can be used for $CO_2$-EOR operations within the structure Samnic-Ghercesti-Malu Mare.

In order to define the offshore solution, first step was to identify the ports along the Danube which have the necessary infrastructure to facilitate the transport of $CO_2$ by ship to the Black Sea. 17 ports have been identified, from which 11 are only fluvial, 3 are fluvial-maritime and 3 maritime.

Within the Black Sea, the major structural unit that accommodates oil reservoirs and potential storage structures and the only structure investigated so far from the $CO_2$ storage perspective is the Histria Depression. The oil reservoirs that can be used for injection and utilization of captured $CO_2$ for EOR are: Lebada West and Lebada East, Sinoe, Portita, Pescarus and Delta.

The CCUS pathways identified for Oltenia cluster presented in this deliverable, both local (onshore) and offshore solutions, will be analyzed in terms of emission reduction potential, estimated costs and oil recovery potential. The results of this analysis will be presented in deliverable D5.5.2 from the ALIGN CCUS project.

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