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ECO-BASE

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Establishing CO_2 enhanced oil recovery Business advantages in South Eastern Europe

Collaborative Project under the ERA-NET ACT programme

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Project Consortia

Organisations:

NORCE

TNO

METU PAL

GeoEcoMar

CO_2Club Romania

PicOil Info Consult

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EXECUTIVE SUMMARY

The Paris Agreement calls for greenhouse gas emission regulations consistent with keeping the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the increase to 1.5 °C. Capturing CO_2 from industrial plants and permanently storing it in the subsurface (CCS) is an essential part of reaching this target, and commercial utilization of the captured CO_2 is one of the mechanisms to create revenues, and hence, support the business case for CO_2 storage.

The objective of the ECO-BASE project was to investigate the potential of commercially deploying carbon capture, utilization and storage (CCUS) by screening available data, developing CCUS roadmaps and exploring for potential CO_2 Enhanced Oil Recovery (CO_2-EOR) pilots in South-East Europe (SEE). ECO-BASE has assessed the potential for CCUS (i.e. CO_2-EOR) through the following activities:

- Creating an inventory of CO_2 sources (potential capture projects) and sinks (potential sites for CO_2 usage through CO_2-EOR) in Romania and Turkey;
- Identifying possible source/sink clusters and performing case studies to evaluate the business potential of combining CO_2-EOR and permanent CO_2-storage;
- Setting up regional CCUS development plans through CO_2-EOR roadmaps;
- Organizing knowledge transfer workshops for local CCUS stakeholders.

Through selected case studies in Romania and Turkey, the ECO-BASE project provided insight into prospective revenue streams and business models for CO_2-EOR in SE-Europe, with a long-term view to large-scale CCUS regional deployment. The project was financed in part by the EU ACT programme, and carried out by organizations in Turkey, Romania, the Netherlands, and Norway.

The case studies focused on the technical and business aspects of CO_2 emitters and oil field operators, potentially in demand for CO_2, to analyse the full value chain, but also included executing an environmental impact study and the assessment and development of the public perception over the duration of the ECO-BASE project.

A prerequisite for realizing a CCUS/CO_2-EOR chain, i.e. with the CO_2 captured from industrial plants, is that all actors along the value chain have a positive business case. This includes the emitter capturing CO_2, the CO_2 transport operator that operates the pipeline, ship, or trucking facilities, and the operator of the oil reservoir where the CO_2 is utilized and stored. The business cases are typically assessed by defining a series of key performance indicators, with quantitative estimates of how the activity, as defined by a series of alternative decision pathways, may lead to positive future discounted cumulative net cash flows (NPV), including the associated uncertainties. The basic premise of a rational investment decision process is that the internal rate of return must exceed each company's weighted cost of capital, plus a risk and a profit margin. Business risks were identified and quantified, with due regard to the 'first of a kind' infrastructure nature and commercial complexity of these projects.

Methodology

In most commercial companies, the process of maturing investment projects is handled through a set of Decision Gate Reviews. At each decision gate, senior management decides to either cancel the project, or to move forward to the next phase, with or without special conditions. This process provides a controlled way of monetizing a business opportunity by moving along a series of well-defined project steps from first idea to technical and economic feasibility, concept selection, detailed design, Final Investment Decision (FID), development, operation and, finally, post implementation review and lessons learned.

As part of the technical and economic cluster analysis in Romania and Turkey, two detailed cases were selected as representing the ‘low hanging fruit’ and potentially providing the business incentive to initiate a ‘first-of-a-kind’ infrastructural project in their respective regions. A problem was however that only a limited amount of oil field data was publicly available, and that other field-specific data was not made available to ECO-BASE. To complete the case studies, the scarce published data from the actual sites were combined with publicly available correlations on how reservoir oil may benefit from CO_2-EOR. This was complemented by a detailed uncertainty analysis to compute ranges of possible outcomes (KPIs).

Cluster selection

As a first Romanian CCS chain, the Brădești oil field in Oltenia-West, Romania, was selected as a potential CO_2-storage, together with the nearby Işalniţa coal-fired power plant. This first CCS chain could at some later stage be extended to other oil fields and CO_2 emitting industries. The cluster of potential sources and sinks is located in a region producing over 30% of the national energy output and responsible for a significant share of the national industrial emissions (almost 35%). This initial CCS chain would capture the CO_2 at the powerplant, transport it by a 15 km pipeline to the Brădești oil field, where it would be used for CO_2-EOR, and eventually store the CO_2 permanently in the oil-bearing layers. The business case was evaluated from the perspective of the oil field operator: at which CO_2 wellhead price (as mutually agreed in a long-term contract between the emitter and the oil field operator) would he have a positive business case with an IRR that is commensurate with the investment risk incurred? In other words: what would be the oil field operator’s ‘Willingness To Pay’ (WTP) for CO_2 delivered at the wellhead? The perspective for the power plant operator was: can this WTP wellhead price yield an IRR that is commensurate with the investment risk for a capture plant? For the pipeline operator, it was assumed that only his costs (discounted CAPEX + OPEX) needed to be recovered through a tariff per ton of CO_2 transported.

The ‘Turkish case’ consisted of analyzing whether one could economically prolong the ongoing CO_2-EOR operation in the Batı Raman oil field using captured anthropogenic CO_2 rather than the CO_2 from the depleting natural gas deposit in the Dodan natural CO_2 reservoir. The Dodan CO_2 reservoir will soon be unable to meet CO_2-demand from the Batı Raman oil field, and an alternative source is required to continue the CO_2-EOR operation. Dodan is connected to the Batı Raman field through an 82 km long pipeline. The Batı Raman oil field is a well-documented case, it is the largest oil deposit in Turkey with approximately 300 Million standard m3 of oil in place and, although the oil production has been going through phases of pressure decline, water injection and, since 1986, a combination of infill drilling and continuous CO_2 injection, the average recovery factor reached some 6% only in 2011. In our case study, two CO_2 sources were considered: the oil refinery in Batman and the cement factory in Kurtalan, both located in the vicinity of the existing CO_2 transport infrastructure between the Dodan field and the Batı Raman oil field.

Results - Romanian Case

Brădești is an oil field discovered in 1970 and that started production in 1971. It is currently approaching its end of life. Oil is produced from the Triassic, Sarmatian and Dogger formations. For the ECO-BASE case study, only the Triassic formation was considered as EORStore reservoir. The Işalniţa coal power plant is located only some 15 km away from the Brădești oil field and, consequently, the costs of connecting the two by a CO_2 pipeline, i.e. if the power plant were to be equipped with a CO_2 capture plant, would be relatively low. Nevertheless, the risk of developing this early infrastructure is considered high and no plans have been formulated to date.

Due to the unavailability of field-specific data and the lack of production history, analogue data from selected CO_2-EOR projects in the United States was used in order to estimate the Brădești reservoir behaviour under CO_2 flooding conditions. The type curves were generated using an industry standard reservoir simulator. To assess the uncertainty in CO_2-EOR reservoir performance, three different type curves were generated for assumed low, medium, and high incremental oil recovery cases (Figure 1). These curves were used in all economic evaluations of the Romanian case and supplied to the ECCO tool according to the decision tree given in Figure 2.

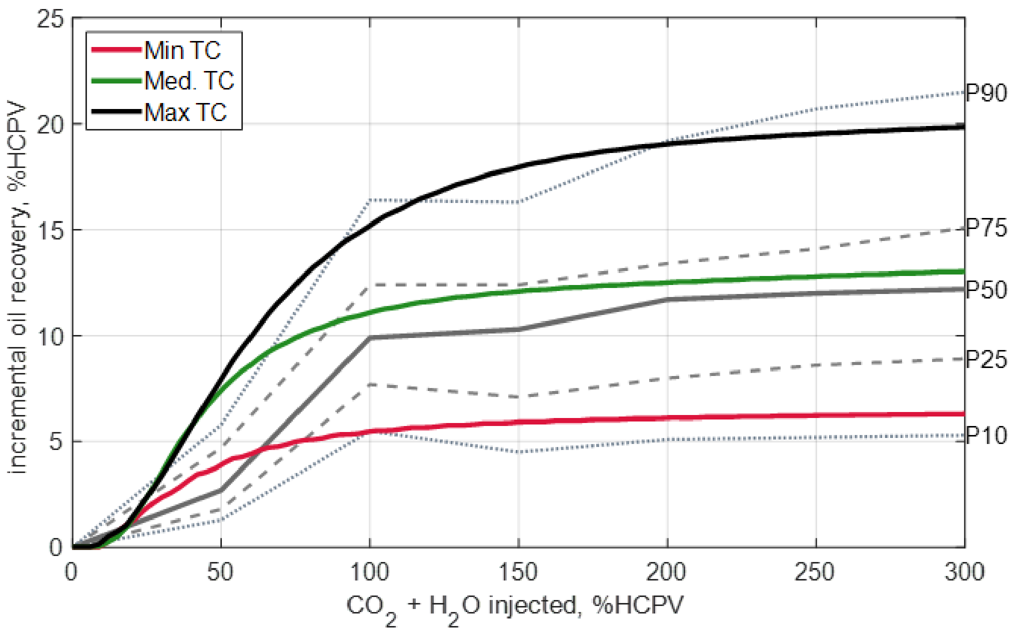

Figure 1. Minimum, median and maximum type curves of incremental oil recovery compared with percentiles for historical US projects used in ECO-BASE simulations for the Romanian case.

To analyse the Romanian case of capturing CO_2 at the Işalniţa power plant and transporting the CO_2 to the Brădești oil field, the main alternative decisions, and main uncertainties (scenarios) were framed. This resulted in the decision tree displayed in Figure 2 below.

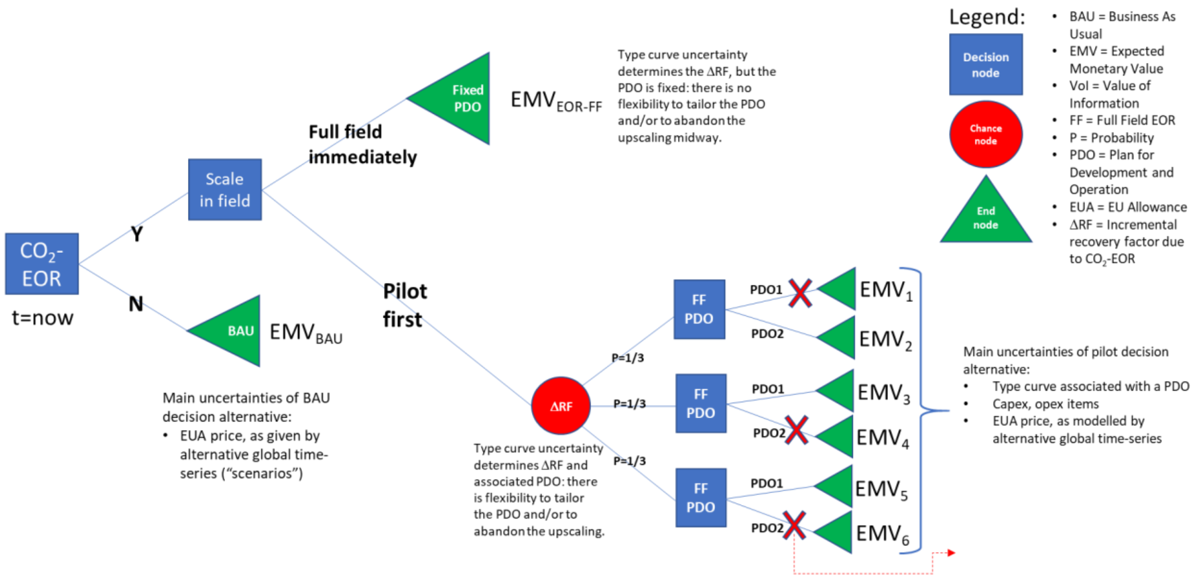

Figure 2. Decision tree for the Romanian case with several scenarios defined: Business as usual, immediate full field implementation of EORStore, and application of EORStore after pilot testing

As can be seen from figure 2, three options were identified from the perspective of the Brădești field operator: to continue with business as usual (BAU, i.e. continue water injection), to deploy CO_2-EOR over the full field from the onset of CO_2 injection operations, thereby assuming all risks deriving from this decision (mainly the uncertainties related to the reservoir performance), or to start with a 5-year pilot prior to full field deployment. Our simulations showed that in either case deploying CO_2-EOR is more profitable than the business as usual case. However, the NPV is quite sensitive to the unknown future oil price and to the poorly known characteristics of the reservoir (note again that the reservoir characteristics assumed had to be estimated as no access to the operator's confidential reservoir data was obtained, and we had to resort to analogue data). Obviously, the BAU case carries the lowest risk. However, BAU also implies the lowest average NPV ('expected monetary value' or EMV). To further assess the risk vs. reward relationship, the CO_2-EOR case was subjected to a sensitivity analysis offsetting the full field deployment from the onset vs. pilot testing first. Implementing full field CO_2-EOR from the onset is on average more profitable, however this comes at a larger risk than doing a pilot test first. Reservoir performance (as described by the type curves in our methodology) is the key factor influencing the economic performance of the operation (as can be seen in Table 1 by comparing the NPVs of the different type curves). Should the pilot test prove the low type curve to be applicable, then capex savings of 8.5 M€ (9.13-0.66) are possible by striking the 'exit option', i.e. not upscaling the CO_2-EOR operation to the full field. Starting with a pilot test comes at the cost of present value from the immediately upscaled project, but allows the risks related to reservoir behaviour to be managed. Moreover, a pilot may also yield additional information (on reservoir performance, practical operational issues, etc.) that allows the full-scale development to be optimized further. This trade-off between present value on the one hand, and risk mitigation + upside management on the other hand, generally is in favour of conducting a pilot test prior to full-scale development.

Results - Turkish Case

The Batı Raman heavy oil field commenced production in 1961 and due to its low gravity (12° API) and high viscosity (600 cP) only 1.7% of the OIIP (of 1850 million stock tank bbl) had been produced until 1986 by primary recovery mechanisms (i.e. pressure depletion). As a result, enhanced recovery mechanisms were investigated and CO_2-EOR emerged as the most promising recovery mechanism (Figure 3). The CO_2 originated from a nearby natural CO_2 gas field, named Dodan, and transported to the oil field for injection into the oil column. Until 2011, the oil production increased to around 110 million bbl (around 6% of OIIP) as a result of immiscible CO_2 flooding, and further CO_2 injection increased the cumulative oil recovery to 130 million bbl in 2020. Since the early 2000s, the yearly oil production rate has been increased by an extensive infill drilling program. This increased demand for CO_2 from the natural deposit in Dodan is reason for concern as due to pressure depletion in Dodan the CO_2 injection rates soon will no longer be sustainable. To prolong the high oil recovery rates from Batı Raman, new sources of CO_2 are required (especially from 2024-2026). We analyzed the Turkish case under the assumption that CO_2 would either be captured from the refinery in Batman only, or from both the refinery and the cement plant in Kurtalan (note that the Kurtalan cement plant straddles the existing CO_2-pipeline from Dodan). The captured CO_2 is assumed to be piped to the Batı Raman oil field. After framing, the main alternative decisions and main uncertainties are represented in the decision tree of Figure 3.

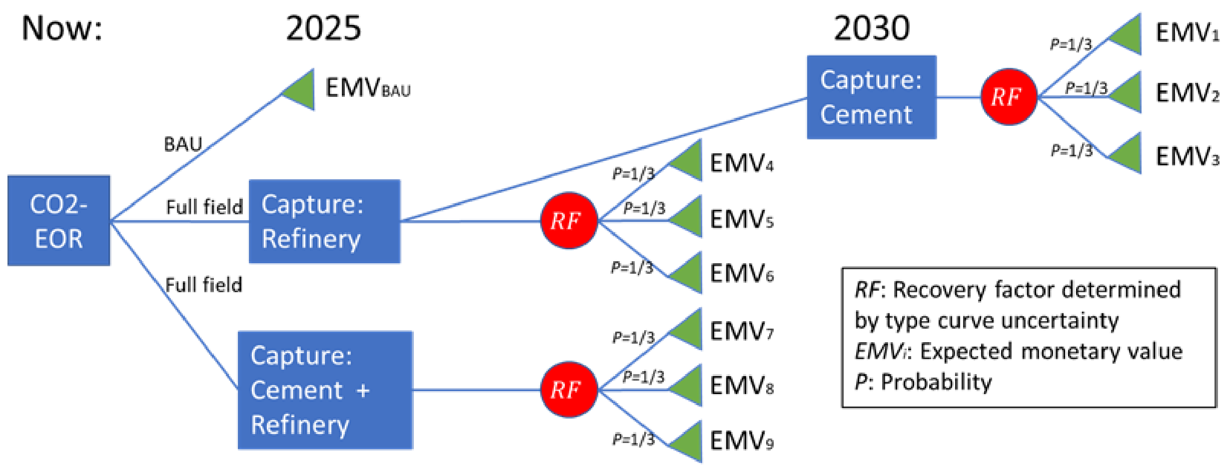

Figure 3. Decision tree for the Turkish case with business as usual and two capture scenarios: capture from cement plant and refinery starting at 2025, and capture from refinery in 2025 and from the cement plant in 2030.

Using the historical data provided by Sahin et al. (2012), type curves were generated that relate cumulative oil production to the injected CO_2 (Figure 4). This was done by fitting a logistic (or analytical) function used as input to the ECCO tool. The ratio of the cumulative CO_2 stored to the cumulative CO_2 injected, i.e. the retention factor, was also calculated as 26.9% using the historical data. The back-produced CO_2 is separated, re-compressed and re-injected into the oil reservoir in combination with the CO_2 delivered from the pipeline. Thus, the rate of CO_2 injected exceeds the CO_2 captured from the cement plant in Kurtalan and refinery in Batman. For the estimation of future oil, CO_2 and water production from the CO_2 injection rate, these types curves were used by the ECCO tool.

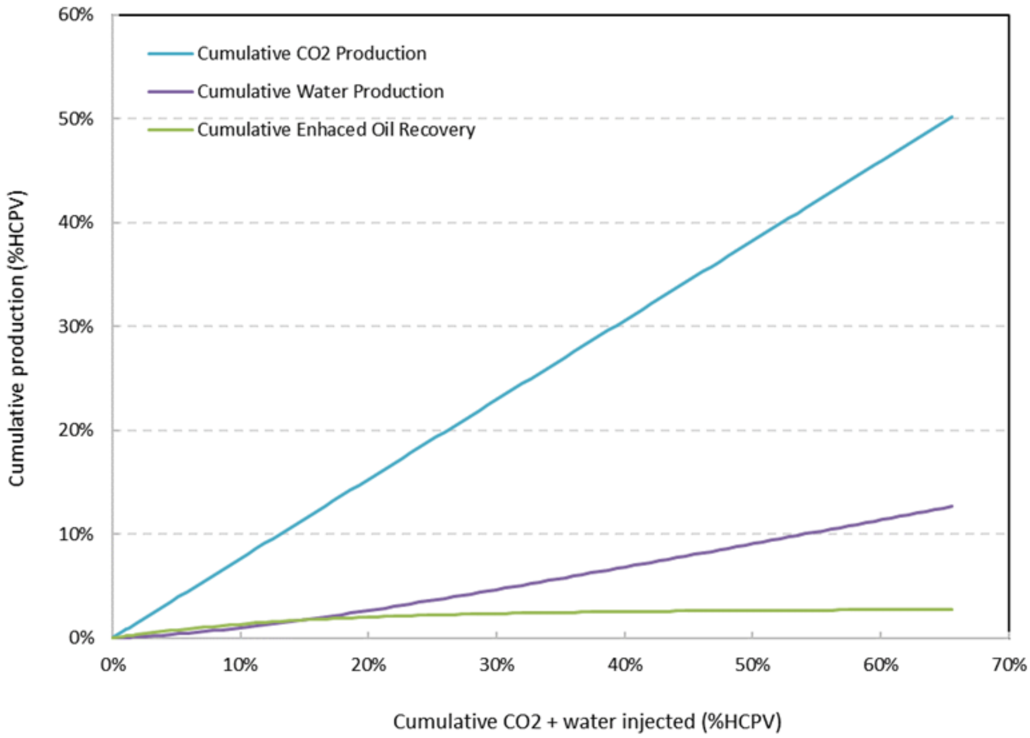

Figure 4. Type curves used in the ECCO tool to calculate the production of oil, water, and CO_2 as a function of cumulative CO_2 and water injected. It forms the basis for the economic cash flow calculations. The type curves were calibrated to the historical CO_2-injection and oil-production data from the Batı Raman oil field.

The work proceeded to compute the various decision pathways and carry out the uncertainty analysis. When considering how to continue with CO_2 for EOR in the Batı Raman field, four decision pathways were simulated, namely 1. the business as usual case (i.e., to deplete Dodan in 2026); 2. source the CO_2 from the refinery in Batman from 2025 onwards; 3. complement option 2 with the option to additionally source the CO_2 from the Kurtalan cement factory in 2030; vs. 4. use both CO_2 sources immediately from 2025. For the base oil price scenario, the outcomes are almost the same, while when the oil price follows the high trend, the refinery capture from 2025 and simultaneous capture from the refinery and cement factory from 2025 are most profitable with the lowest financial risk.

Conclusion

The main merit of the ECO-BASE project is that for the first time a methodology was developed and applied to actual case studies, despite the limited accessibility to field-specific data. This enabled the ECO-BASE team of researchers to assess the economic feasibility of CO_2 capture from industrial plants in Romania and Turkey, with CO_2 capture and transport to nearby producing oil fields. At the oil fields the CO_2 is injected both for Enhanced Oil Recovery purposes and for permanent sequestration of the CO_2 (the so called 'EORStore' concept). The methodology developed and presented to stakeholders in Romania and Turkey (i.e. government and industries) was aimed at initiating a discussion on possible next steps to further mature the concept of EORStore in Romania and Turkey.

Although actual available field data were limited, or even inaccessible due to their confidential nature, it can be argued that, potentially, significant amounts (up to tens of million tons) of CO_2 can be permanently stored in the oil reservoirs, and that this can be achieved under economically profitable conditions. This is because only a fraction of the injected CO_2 is back-produced, and then separated, compressed and re-injected. In the end, all the CO_2 transported to the field ends up in the ground, and significant value is generated to all stakeholders in the CCUS-chain by the incremental oil sales and, in case of Romania, the avoidance of having to purchase emission rights by the coal-fired power plant. Investments risks are manageable and seem commensurate with the reward, as given by the IRR decision metric. Stakeholders are encouraged to further investigate these possible business advantages and mature the concept to a next stage.

These 'first-of-a-kind' projects also address the role of the government to stimulate the development of an initial CO_2 infrastructure by providing guarantees and, if necessary, also subsidies. Follow-on projects in the designated potential regional CCS clusters, West-Oltenia in Romania and Batı Raman in SE Turkey, could profit from this initial infrastructure and would incur less risk. Although one could argue that incremental oil production is inconsistent with CCS, as the incremental oil will lead to incremental CO_2 emissions, the rationale is that EORStore provides a means to finance the initial, first-of-a-kind CO_2 infrastructure, which otherwise would not have been realised.

It can be concluded that, in South Eastern Europe, CO_2-EOR has the potential to justify economically first-of-a-kind CO_2 infrastructure and sequestration projects that would not have been feasible without the CO_2 usage by producing oil fields.

The ECO-BASE project addressed the ACT calls thematic area of 'Utilisation'. The project contributed to CCS knowledge transfer across Europe from Norway and Nederland to Turkey and Romania. ECO-BASE has taken into account the larger picture of CCUS through CO2-EOR, not only by mining data, pairing emitters and sinks, but also by investigating field clusters and setting up a framework for roadmaps and a sophisticated and traceable way to rank CO2-EOR potential.

A contact with potential stakeholders was established and an interest from oil and gas, energy, refinery and cement producing company was registered. The team is currently looking at financing possibilities in EU Innovation Fund or Horizon Europe.

Project structure

The objective of the ECO-BASE project was to investigate the potential of commercially deploying carbon capture, utilization and storage (CCUS) by screening available data, developing CCUS roadmaps and exploring for potential CO_2 Enhanced Oil Recovery (CO_2-EOR) pilots in South-East Europe (SEE). ECO-BASE has assessed the potential for CCUS (i.e. CO_2-EOR) through the following 4 sub-projects:

- SP1 Mapping potential
- SP2 Optimisation of EORStore: creating a business case
- SP3 Knowledge transfer
- SP4 Public awareness and acceptance

All project partners contributed to all sub-projects with METU PAL focusing on Turkish case and GeoEcoMar, CO_2Club Romania and PicOil Info Consult on Romanian case. TNO coordinated SP1, NORCE SP2, GeoEcoMar SP3 and CO_2Club Romania SP4.

This final report will summarize the activities executed in all of them. For a more in depth review we suggest reviewing the deliverables resulting directly from the sub-projects.

SUB PROJECT 1. Mapping potential.

Work under Sub-Project 1 comprised the following activities.

Inventory of source and sink capacities

Work on ECO-BASE started by investigating the pilots and feasibility studies that have already been performed in the SEE region. These projects as well as other national and regional studies in SEE region gave valuable information and data to be included in the database. Carbon capture and storage (CCS) has a high potential of reducing CO_2 emissions, but it is still a slow-moving technology. At present, the only industry scale CO_2 storage projects actually storing CO_2 in Europe are the Sleipner and Snøhvit projects in Norway. Nevertheless, new initiatives are being developed in Norway, in the UK and The Netherlands. Storage potential has been mapped at varying levels of detail in the North Sea and the potential for CO_2-EOR has been the subject of research for several decades.

Source and sink capacities in Turkey:

In Turkey CO_2-EOR is a well-known process applied by the state petroleum company since 1986, the sole aim has been the increase of oil recovery. CCS is not taken into consideration in any national policy document. Therefore, there is also no law regulating CCS. In Turkey the most obvious choice was Bati Raman field, where natural CO_2 injection was carried out since 1986 and resources of natural CO_2 are almost depleted. Adiyaman cluster comprised of the regional oil fields and several cement / energy producing industries was evaluated as well. Adiyaman regions is a rapid growing area with ongoing urbanization. However, experience with CO_2 injection at Bati Raman was a decisive factor.

Source and sink capacities in Romania:

Romania has the potential to become CO_2 negative. This is the conclusion of a report, "Our future is carbon negative – A CCS Roadmap for Romania", published by Bellona Foundation (erena et al, 2012). The report models the Romanian electricity system until 2050 by considering current energy plans, with CCS added. Apparently, the large availability of sustainable biomass in Romania gives the country the unique potential for CO_2 negative electricity. After inventory was created 6 potential clusters were identified as shown in Figure 5.

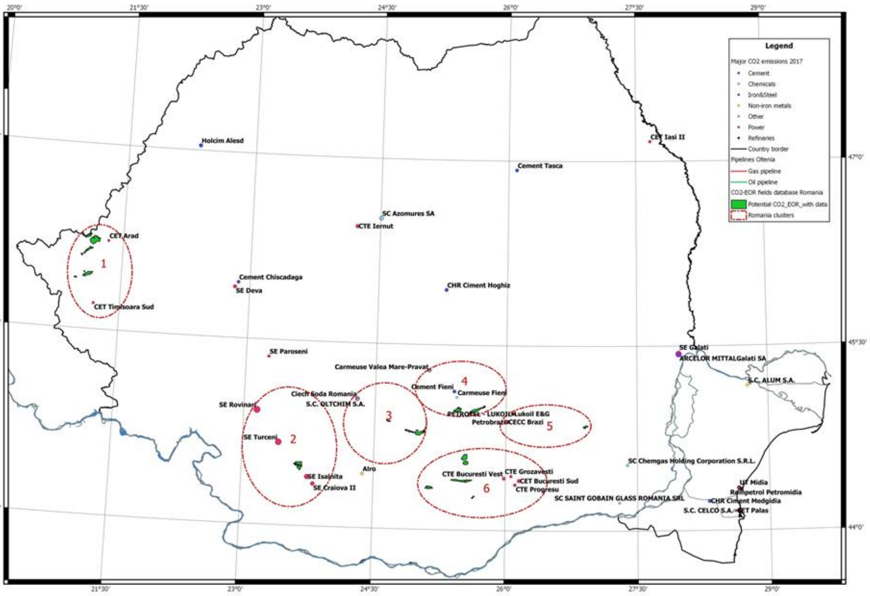

Figure 5. Regional clusters for EORStore in Romania

Source and sink capacities in Greece:

Studies have pointed to opportunities for CCUS, in the form of CO_2-EOR, but so far, no initiatives have been undertaken to develop these to real projects. CCS currently has no clear role in government plans for energy system reform or emission reduction. CO_2-EOR seems relevant for all three countries. It is being deployed in Turkey, using CO_2 from a natural source, but only with the goal of EOR. The process has been studied in Greece but is not currently deployed. Data on the subsurface may not be readily available. There is potential in supporting the inclusion of CCS in national policies.

Environmental impact assessment

The anticipated effects of the CO_2-EOR on the environment have been assessed. The work has been reported in deliverable D1.7. The results have been split up in two parts:

1. Guidance based on a literature review on environmental impact assessment for CO_2-EOR including mitigation actions when CO_2-leakage would occur;
2. A practical description of the possible environmental impacts of the CO_2-EOR part of the regional CCUS cluster case based on this guidance.

Database development

Based on knowledge gained in a review of other projects a database was setup. The database was to be used later in the project.

ECO-BASE adopted the database structure as used in and developed by the CO_2STOP project, which aimed to produce an up-to-date and publicly available database of CO_2 storage options in the EU. Within ECO-BASE additional data on sources and sinks was gathered, technical risks were assessed, environmental aspects and regulatory and legal aspects were analysed.

GIS-based maps were created based on the gathered data. This was done in such a way that it is easily visible where sources and sinks are located, what amounts of CO_2 where involved, timing of sources and sinks was included and the reliability/uncertainty level of the data was accessed

CO_2-EOR roadmaps

Objectives were to identify and match industrial clusters and CO_2 sources, industrial as well as natural. To create inventories of legislation and incentives and identify potential legal and technological bottle necks. To identify storage and EOR potentials and to create roadmaps for the development of CCUS in specific clusters. The activity was transferred to SP2 in order to provide more detailed and concrete plans for clusters selected.

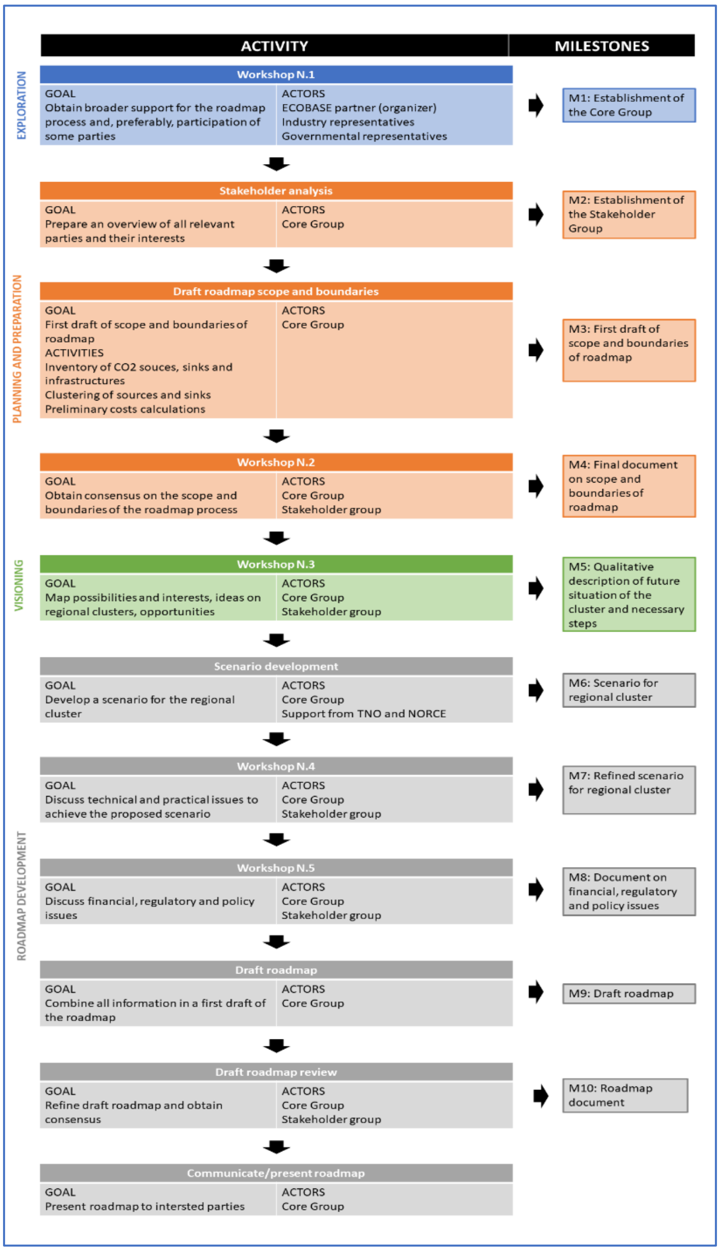

Figure 6: Scheme of the ECO-BASE roadmapping process

Using the maps developed in the earlier stages of the project, source and sink clustering was performed. The matching was based on capacities as well as timing of availability, but also, the uncertainty and reliability of the data was taken into account.

In order for CO_2-EOR to move beyond research, business cases are required which consider other aspects than the source and sink capacities. Roadmaps will support the development of business cases by taking into account aspects other than the technical ones. In ECO-BASE we developed a framework (Figure 6) which can be used to create cluster-specific roadmaps in an organised way. The framework covers aspects concerning infrastructure, economics, environment, regulations, risks, politics, public awareness and perception and the development of storage capacity. Any resulting roadmaps should in general be regionally oriented and dedicated to exploring CO_2-EOR business cases and their purpose is to clarify and illustrate which steps need to be taken to realise those business cases.

Decision tree for ranking CO_2-EOR potential

For CO_2-EOR to happen, all actors in the value chain must commit to the project, that is from the emitter capturing CO_2, transport operator that operate pipeline/ship/trucks facilities, and to the reservoir operator where CO_2 is utilized and stored. All actors need to have acceptable and positive business cases before a commitment is made. The business cases are typically based on defining key performance indicators, and then quantitative estimate for how the activity led to positive future cash flows (FCF) and discounting rate for net present value (NPV). The basic premise of a rational decision process is that the internal rate of return needs to exceed the weighted cost of credit, plus a safety margin. Within SP1 we illustrated the creation of the decision tree from the field operator's perspective. Decision trees represent a structured way of providing insights into the process and parameter uncertainty that affects the outcome of a series of decisions. The trees are used for decision support, where the structured way of displaying conditional probabilities are shown in an instructive way.

After the framing process the decision tree analyses was performed. Many possible scenarios and main uncertainties emerge because of the alternative decisions that can be made during the development of a CO_2-EOR project.

Selecting clusters for further studies.

As a first Romanian CCS chain, the Brădești oil field in Oltenia-West, Romania, was selected as a potential CO2-storage, together with the nearby Işalniţa coal-fired power plant. This first CCS chain could at some later stage be extended to other oil fields and CO2 emitting industries. The cluster of potential sources and sinks is located in a region producing over 30% of the national energy output and responsible for a significant share of the national industrial emissions (almost 35%). This initial CCS chain would capture the CO2 at the powerplant, transport it by a 15 km pipeline to the Brădești oil field, where it would be used for CO2-EOR, and eventually store the CO2 permanently in the oil-bearing layers. The business case was evaluated from the perspective of the oil field operator: at which CO2 wellhead price (as mutually agreed in a long-term contract between the emitter and the oil field operator) would he have a positive business case with an IRR that is commensurate with the investment risk incurred? In other words: what would be the oil field operator's 'Willingness To Pay' (WTP) for CO2 delivered at the wellhead? The perspective for the power plant operator was: can this WTP wellhead price yield an IRR that is commensurate with the investment risk for a capture plant? For the pipeline operator, it was assumed that only his costs (discounted CAPEX + OPEX) needed to be recovered through a tariff per ton of CO2 transported.

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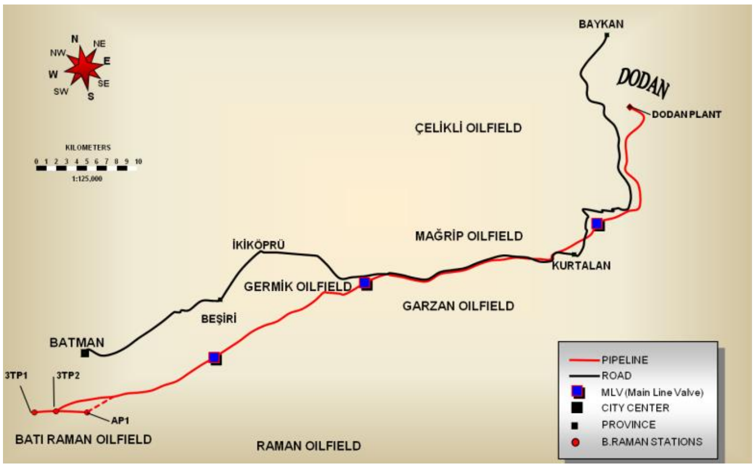
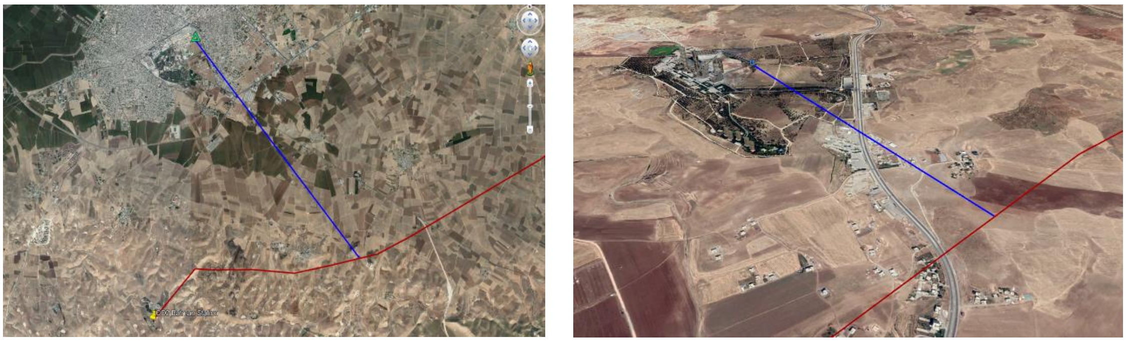


Figure 7. Pipeline between Dodan and Bati Raman Fields



Tüpraş Refinery to Dodan CO_2 Pipeline: 8 km
Estimated emission: 75 Mtonne CO_2/year

Limak Cement Factory to Dodan CO_2 Pipeline, 1.8 km
Estimated emission: 400,000 tonne CO_2/year

Figure 8. Potential sources of antropogenic CO_2 in Bati-Raman cluster.

The SP2 activities will aim towards bringing the two clusters closer to positive DN1 decision by providing first CCUS trough CO_2-EOR evaluations for the future stakeholders.

Deviations from proposed work plan

During the project meeting in 2018 the ECO-BASE team discussed and later proposed to ACT consortium to move the road-mapping exercise to the SP2 in order to make the roadmaps more specific for selected clusters. The suggestion was accepted by ACT consortia.

SUB PROJECT 2. Optimisation of EORStore: creating a business case

The objective of SP 2 of the ECO-BASE project was to come up with concepts and initial techno-economic analysis (TEA) for the first CCUS (carbon capture utilisation and storage) projects in Turkey and Romania and initiate discussions between key local stakeholders. Unlike in the USA, where an extensive infrastructure related to CO_2-EOR (enhancing oil recovery by injecting CO_2 into oil reservoirs) has been built up over several decades Edwards et al, 2018), CCUS facilities in Europe[1] are

[1] "The potential for CCS and CCU in Europ," 32nd meeting of the European gas regulatory forum, 5-6. JUNE 2019. Coordinated by IOGP, https://ec.europa.eu/info/sites/info/files/iogp_-_report_-_ccs_ccu.pdf, 2019

largely local in scale. ECO-BASE has worked on two “first of a kind” (FOAK) case studies selected in SP1 to investigate the business potential for CO_2-EOR projects with associated permanent CO_2 storage (EORstore). The main goal of this SP is to achieve a first steppingstone towards answering the question at the first decision gate: Is there a business case?

Modelling approach

In most commercial companies, the process of maturing investment projects is handled through a set of Decision Gate Reviews. At each decision gate, senior management decides to either cancel the project, or to move forward to the next phase, with or without special conditions. This process provides a controlled way of monetizing a business opportunity by moving along a series of well-defined project steps from first idea to technical and economic feasibility, concept selection, detailed design, Final Investment Decision (FID), development, operation and, finally, post implementation review and lessons learned.

As part of the technical and economic cluster analysis in Romania and Turkey, two detailed cases were selected as representing the ‘low hanging fruit’ and potentially providing the business incentive to initiate a ‘first-of-a-kind’ infrastructural project in their respective regions. A problem was however that only a limited amount of oil field data was publicly available, and that other field-specific data was not made available to ECO-BASE. To complete the case studies, the scarce published data from the actual sites were combined with publicly available correlations on how reservoir oil may benefit from CO_2-EOR. This was complemented by a detailed uncertainty analysis to compute ranges of possible outcomes (KPIs).

To explore and quantify the potential opportunities the following workflow was followed:

- First, frame the alternative decision pathways for each case study, describe the main uncertainties (physical and/or economical), establish the possible economic scenarios, and create the corresponding decision tree. Decision trees combined with probabilistic analysis represent a structured way of providing insight in how to address the risks and opportunities resulting from model input parameter uncertainties and from the selected series of (controllable) decisions. They also provide a structured way of optimizing the business case.

- Second, evaluate the decision tree using an existing, analytical tool named ECCO-tool (Lovseth et al, 2011). The ECCO-tool is an integrated technical/economic CCS multi-actor, multi-asset value chain assessment tool and was developed during the ECCO project (Petter et al, 2009). It was made available to ECO-BASE project partners. When properly conducted, many possible scenarios (uncertainties) emerge during the framing process and can be combined with alternative decisions that can be made when monetizing a project. Also, decisions that respond to future information being revealed as time progresses can be included.

- The third step in the workflow is to collect the pertinent data and to estimate the uncertainties in the project. For example, the published historical CO_2-EOR reservoir performance of the Turkish case, but also analogue data, published correlations (Verma et al, 2017) etc. were used and combined with complementary reservoir numerical simulation modelling performed by the ECO-BASE team. This resulted in a series of EOR “Type Curves (TCs)”, that relate the cumulative hydrocarbon pore volume of CO_2-EOR oil, water and CO_2 produced, on the one hand, to the cumulative hydrocarbon pore volume of CO_2 injected, on the other hand (the latter was used in the Turkish case). In case of water-alternating-gas injection (WAG-injection), the combined impact of CO_2 and water injection can be related to produced volumes (this was used in the Romanian case). These type curves were supplied to the ECCO tool and used to estimate the EOR incremental oil as a function of time and as a result of the rate at which CO_2 (and water) is injected. The total field CO_2 storage capacity, extra oil produced by the EOR operation etc. was estimated using a combination of material balance and reservoir simulation modelling, where the fraction of back-produced CO_2 was used to estimate the CO_2 'lost' to the formation (i.e. assumed permanently stored).

- For the Romanian case, the mass balance of injected CO_2 and water, and produced CO_2, water and hydrocarbons, was used to evaluate under different injection and production rates the overall economy for the field operator. To compute the economics, the field operator was assumed to purchase CO_2 at a wellhead price that meets the costs required for the capture and transport operators to have a positive business case. In addition to the CO_2 wellhead price, a series of other OPEX and CAPEX cost elements were included for the oil-field operator (related to well costs, various opex costs, separation and re-compression of back-produced CO_2 etc). The revenue for the oil field operator consisted of the sales of the incremental oil production, i.e. the oil in addition to the production without CO_2-EOR. Cost elements for the handling of (back-)produced fluids, i.e. the separation, compression and re-injection of CO_2 were included in the analysis. For the emitter (a nearby coal-fired power plant), revenue consisted of the savings from not having to purchase emission rights on the ETS, and from the sales of CO_2 to the oil field operator.
- Finally, uncertainty and sensitivity analyses were carried out using the Monte Carlo functionality of the XL statistical plug-in Crystal Ball. This was done to assess the impact of uncertainties in the physical reservoir properties (OIIP), in reservoir performance (type curves), and in the planning and financial parameters (CAPEX, OPEX, revenues, timing) on the various Key Performance Indicators, such as net present value (NPV) and internal rate of return (IRR). For the global parameters (oil price, CO_2 price on the EU-ETS, inflation, CAPEX and OPEX escalators, etc.) time-series were taken from the publication 'Blue hydrogen as accelerator and pioneer for energy transition in the industry' (H-vision report, 2019).

Decision trees and the computations thereof

Romanian Case

Brădești is an oil field discovered in 1970 and that started production in 1971. It is currently approaching its end of life. Oil is produced from the Triassic, Sarmatian and Dogger formations. For the ECO-BASE case study, only the Triassic formation was considered as EORStore reservoir. The Işalniţa coal power plant is located only some 15 km away from the Brădești oil field and, consequently, the costs of connecting the two by a CO_2 pipeline, i.e. if the power plant were to be equipped with a CO_2 capture plant, would be relatively low. Nevertheless, the risk of developing this early infrastructure is considered high and no plans have been formulated to date.

Due to the unavailability of field-specific data and the lack of production history, analogue data from selected CO_2-EOR projects in the United States was used in order to estimate the Brădești reservoir behaviour under CO_2 flooding conditions. The type curves were generated using an industry standard reservoir simulator (ECLIPSE300 by Schlumberger). To assess the uncertainty in CO_2-EOR reservoir performance, three different type curves were generated, i.e. for assumed low, medium, and high incremental oil recovery cases (Figure 9). These curves were used in all economic evaluations of the Romanian case and supplied to the ECCO tool according to the decision tree given in Figure 6.

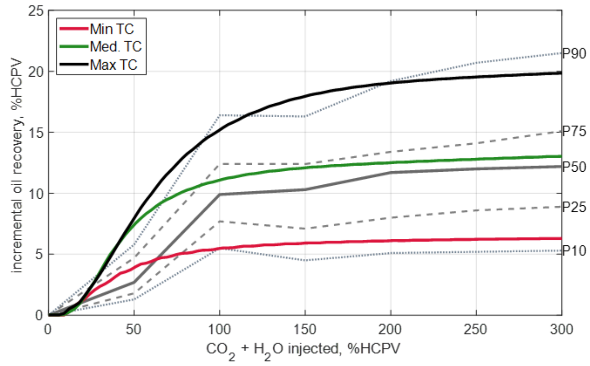


Figure 9. Minimum, median and maximum type curves of incremental oil recovery compared with percentiles for historical US projects used in ECO-BASE simulations for the Romanian case.

To analyse the Romanian case of capturing CO_2 at the Işalniţa power plant and transporting the CO_2 to the Brădești oil field, the main alternative decisions, and main uncertainties (scenarios) were framed. This resulted in the decision tree displayed in Figure 10 below.

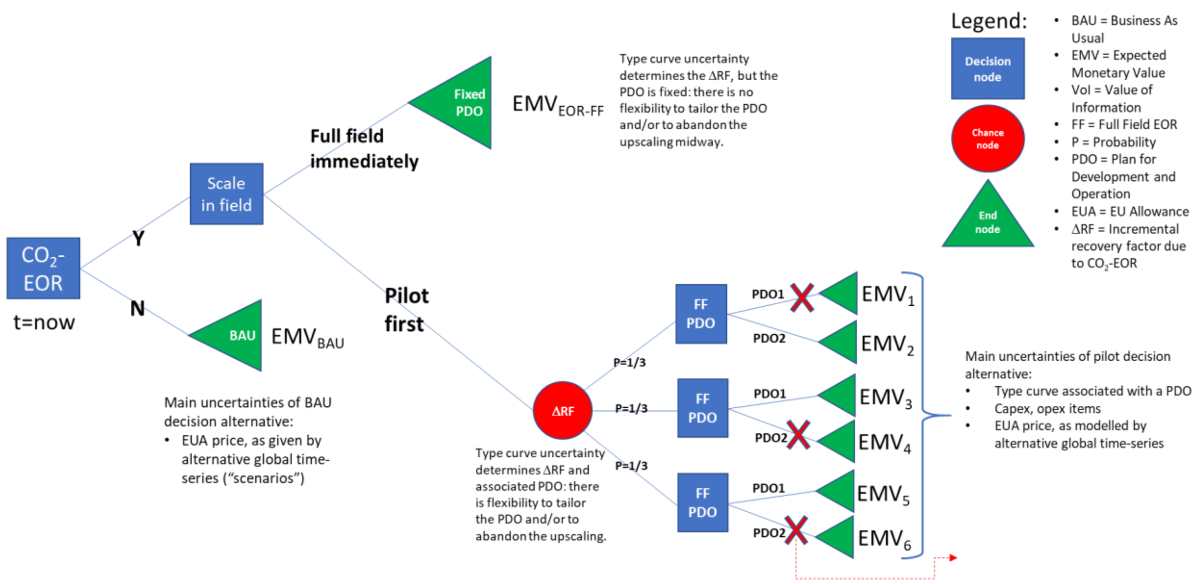


Figure 10. Decision tree for the Romanian case with several scenarios defined: Business as usual, immediate full field implementation of EORStore, and application of EORStore after pilot testing

As can be seen from Figure 10, three options were identified from the perspective of the Brădești field operator: to continue with business as usual (BAU, i.e. continue water injection), to deploy CO_2-EOR over the full field from the onset of CO_2 injection operations, thereby assuming all risks deriving from this decision (mainly the uncertainties related to the reservoir performance), or to start with a

5-year pilot prior to full field deployment. Our simulations showed that in either case deploying CO_2-EOR is more profitable than the business as usual case. However, the NPV is quite sensitive to the unknown future oil price and to the poorly known characteristics of the reservoir (note again that the reservoir characteristics assumed had to be estimated as no access to the operator's confidential reservoir data was obtained, and we had to resort to analogue data). The KPIs assuming a 10% discount rate for the Romanian case are reported for the last year of economic production in Table 3 below.

Table 3. Overview of end results from the reference case simulations for BAU, pilot, full field EOR after pilot and full field EOR from start, respectively. These point estimates represent key performance indicators for the cases modelled with the ECCO tool.

	BAU	EOR full field from start 2025			EOR full field 2030			Pilot 2025-2029 (10% of the field)		
	Water inj.	Low TC	Med TC	High TC	Low TC	Med TC	High TC	Low TC	Med TC	High TC
Last year of production	2044	2037	2041	2045	2042	2046	2051	2029	2029	2029
NPV, M€	67.8	-29.6	269	423.8	-41.6	207.3	365.7	-23.4	-3.9	0.4
CAPEX, M€	n.a.	9.13			8.63			0.66		
Total oil & gas sales (discounted), M€	258.3	463.5	846.8	1093.4	411.5	714.1	941.3	29.1	51.3	56.2
Total Gov. take (discounted), M€	44	83.3	173.2	227.9	81.3	164.2	213	3.5	7.9	9.1
Avg. oil production cost of projected period, €/bbl	29.7	78.8	34.4	28.2	78.3	33	28	65.3	44.6	36.4
Total cost of CO_2 (bought + recycled), M€	n.a.	285.6	372.4	467.2	286.9	361.5	474.9	28.5	25.6	24.5
Total CO_2 bought from Işalniţa, Mt	n.a.	60.2	113.7	160.2	87.4	138.5	181.7	22	22	22
Oil produced by CO_2-EOR, million bbl	n.a.	17.3	36.3	56.6	16.5	34.6	53.2	0.8	1.4	1.6
Additional recovery by CO_2-EOR, % of OIIP	n.a.	5.9	12.4	19.3	5.8	12.2	18.8	5.3	9.5	10.7
Total recovery, % of OIIP	33.8	36.5	44.1	51.4	39.5	47.3	54.2	35.8	40.5	41.5

Obviously, the BAU case carries the lowest risk. However, BAU also implies the lowest average NPV ('expected monetary value' or EMV). To further assess the risk vs. reward relationship, the CO_2-EOR case was subjected to a sensitivity analysis offsetting the full field deployment from the onset vs. pilot testing first. Implementing full field CO_2-EOR from the onset is on average more profitable, however this comes at a larger risk than doing a pilot test first. Reservoir performance (as described by the type curves in our methodology) is the key factor influencing the economic performance of the operation (as can be seen in Table 3 by comparing the NPVs of the different type curves). Should the pilot test prove the low type curve to be applicable, then capex savings of 8.5 M€ (9.13-0.66) are possible by striking the 'exit option', i.e. not upscaling the CO_2-EOR operation to the full field. Starting with a pilot test comes at the cost of present value from the immediately upscaled project, but allows the risks related to reservoir behaviour to be managed. Moreover, a pilot may also yield additional information (on reservoir performance, practical operational issues, etc.) that allows the full-scale development to be optimized further. This trade-off between present value on the one hand, and risk mitigation + upside management on the other hand, generally is in favour of conducting a pilot test prior to full-scale development.

Turkish Case

The Batı Raman heavy oil field commenced production in 1961 and due to its low gravity (12° API) and high viscosity (600 cP) only 1.7% of the OIIP (of 1850 million stock tank bbl) had been produced until 1986 by primary recovery mechanisms (i.e. pressure depletion) (Sahin et al, 2012). As a result, enhanced recovery mechanisms were investigated (Sahin et al, 2012) and CO_2-EOR emerged as the most promising recovery mechanism (Figure 11).

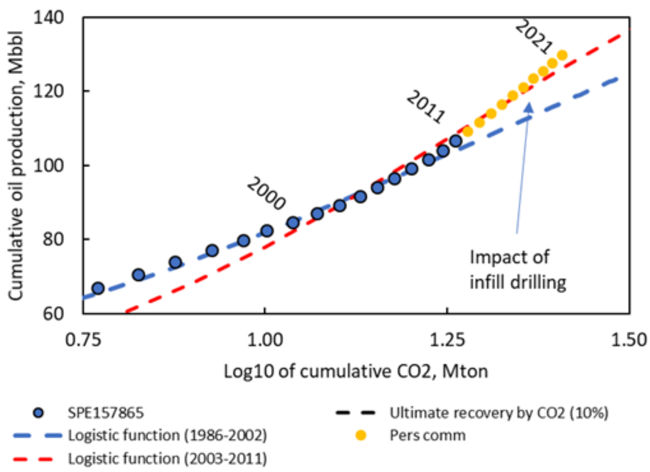


Figure 11. Yearly Batı Raman historical oil production (blue circles) plotted as cumulative oil production vs. cumulative CO_2 injection on a log-linear axis. The red dotted line was used for the future CO_2 driven oil recovery estimations. From 2005 to 2020, an infill drilling program has been ongoing, which will be ceased in 2021.

The CO_2 originated from a nearby natural CO_2 gas field, named Dodan, and transported to the oil field for injection into the oil column. Until 2011, the oil production increased to around 110 million bbl (around 6% of OIIP) as a result of immiscible CO_2 flooding (Sahin et al, 2012), and further CO_2 injection increased the cumulative oil recovery to 130 million bbl in 2020. Since the early 2000s, the yearly oil production rate has been increased by an extensive infill drilling program. This increased demand for CO_2 from the natural deposit in Dodan is reason for concern as due to pressure depletion in Dodan the CO_2 injection rates soon will no longer be sustainable. To prolong the high oil recovery rates from Batı Raman, new sources of CO_2 are required (especially from 2024-2026). We analyzed the Turkish case under the assumption that CO_2 would either be captured from the refinery in Batman only, or from both the refinery and the cement plant in Kurtalan (note that the Kurtalan cement plant straddles the existing CO_2-pipeline from Dodan). The captured CO_2 is assumed to be piped to the Batı Raman oil field. After framing, the main alternative decisions and main uncertainties are represented in the decision tree of Figure 12.

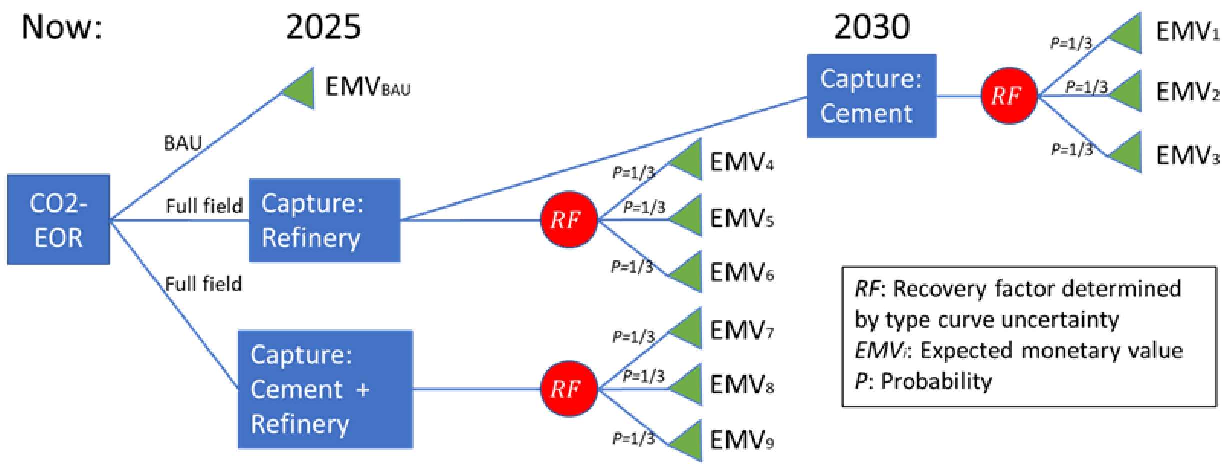


Figure 12. Decision tree for the Turkish case with business as usual and two capture scenarios: capture from cement plant and refinery starting at 2025, and capture from refinery in 2025 and from the cement plant in 2030.

Using the historical data provided by Sahin et al. 2012 in Figure 9, type curves were generated that relate cumulative oil production to the injected CO_2 (Figure 13). This was done by fitting a logistic (or analytical) function used as input to the ECCO tool. The ratio of the cumulative CO_2 stored to the cumulative CO_2 injected, i.e. the retention factor, was also calculated as 26.9% using the historical data. The back-produced CO_2 is separated, re-compressed and re-injected into the oil reservoir in combination with the CO_2 delivered from the pipeline. Thus, the rate of CO_2 injected exceeds the CO_2 captured from the cement plant in Kurtalan and refinery in Batman. For the estimation of future oil, CO_2 and water production from the CO_2 injection rate, these types curves were used by the ECCO tool.

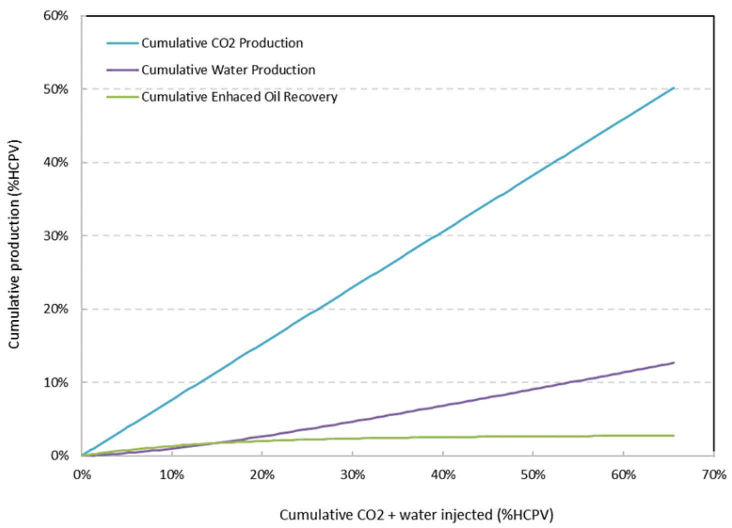


Figure 13. Type curves used in the ECCO tool to calculate the production of oil, water, and CO_2 as a function of cumulative CO_2 and water injected. It forms the basis for the economic cash flow calculations. The type curves were calibrated to the historical CO_2-injection and oil-production data from the Batı Raman oil field (Sahin et al, 2012).

The work proceeded to compute the various decision pathways and carry out the uncertainty analysis. When considering how to continue with CO_2 for EOR in the Batı Raman field, four decision pathways were simulated, namely 1. the business as usual case (i.e., to deplete Dodan in 2026); 2. source the CO_2 from the refinery in Batman from 2025 onwards; 3. complement option 2 with the option to additionally source the CO_2 from the Kurtalan cement factory in 2030; vs. 4. use both CO_2 sources immediately from 2025. For the base oil price scenario, the outcomes are almost the same, while when the oil price follows the high trend, the refinery capture from 2025 and simultaneous capture from the refinery and cement factory from 2025 are most profitable with the lowest financial risk. An overview of the KPIs for the Turkish case is presented in Table 4 with NPVs and other KPIs computed until the last year of production assuming a 10% discount rate.

Table 4. Overview of the key performance indicators for Turkish cluster.

	BAU	Refinery 2025	Refinery 2025, cement 2030	Refinery and cement 2025
Last year of production	2026	2037	2040	2036
NPV, M€	116.6	197.7	287.0	410.4
Total oil sales, M€	322.8	663.8	930.3	1165.7
Total Govt. take, M€	74.1	132.6	189.0	249.4
Average oil prod cost, €/bbl	23.6	31.2	29.4	26.5
Total cost of CO_2, M€	6.0	57.5	112.8	151.1
Total CO_2 stored, Mt	0.6	2.1	5.5	5.38
Oil produced by CO_2, Mbbl	6.83	20.32	37.09	36.87
Total additional recovery	0.37 %	1.10 %	2.00 %	1.99 %

The main merit of the ECO-BASE project is that for the first time a methodology was developed and applied to actual case studies, despite the limited accessibility to field-specific data. This enabled the ECO-BASE team of researchers to assess the economic feasibility of CO_2 capture from industrial plants in Romania and Turkey, with CO_2 capture and transport to nearby producing oil fields. At the oil fields the CO_2 is injected both for Enhanced Oil Recovery purposes and for permanent sequestration of the CO_2 (the so called 'EORStore' concept).

The cases analysed in the project have several principle differences between Romanian and Turkish clusters:

- Lack of technological experience along CCUS value chain in Romania in contrast to ongoing CO_2EOR in Turkey;
- Availability of EOR and storage regulations in Romania in contrast to lack of appropriate legal framework to effectively regulate storage of CO_2 in Turkey;

The methodology developed and its application to selected clusters, presented to stakeholders in Romania and Turkey (i.e. government and industries) was aimed at initiating a discussion on possible next steps to further mature the concept of EORStore in Romania and Turkey.

Although actual available field data were limited, or even inaccessible due to their confidential nature, it can be argued that, potentially, significant amounts (up to tens of million tons) of CO_2 can be permanently stored in the oil reservoirs, and that this can be achieved under economically profitable conditions. This is because only a fraction of the injected CO_2 is back-produced, and then separated, compressed and re-injected. In the end, all the CO_2 transported to the field ends up in the ground, and significant value is generated to all stakeholders in the CCUS-chain by the incremental oil sales and, in case of Romania, the avoidance of having to purchase emission rights by the coal-fired power plant. Investments risks are manageable and seem commensurate with the reward, as given by the IRR decision metric. Stakeholders are encouraged to further investigate these possible business advantages and mature the concept to a next stage.

These 'first-of-a-kind' projects also address the role of the government to stimulate the development of an initial CO_2 infrastructure by providing guarantees and, if necessary, also subsidies. Follow-on projects in the designated potential regional CCS clusters, West-Oltenia in Romania and Batı Raman in SE Turkey, could profit from this initial infrastructure and would incur less risk. Although one could argue that incremental oil production is inconsistent with CCS, as the incremental oil will lead to incremental CO_2 emissions, the rationale is that EORStore provides a means to finance the initial, first-of-a-kind CO_2 infrastructure, which otherwise would not have been realised.

It can be concluded that, in South Eastern Europe, CO_2-EOR has the potential to justify economically first-of-a-kind CO_2 infrastructure and sequestration projects that would not have been feasible without the CO_2 usage by producing oil fields.

Stakeholder meetings

Due to the COVID crisis the stakeholder dialog was delayed till Autumn 2020 and carried out in a series of online meeting and local consultations. Finally, ECO-BASE consortium got a confirmed interest from several industry partners in Romania (Dacian Petroleum and Heidelberg Cement) and Turkey (TUPRAS). A dialogue with Turkish Petroleum corporation, OMV Petrom, and Ișalnița power station was still ongoing at the moment of writing this report.

Partners from Greece who were not able to actively participate in ECO-BASE due to lack of funding has joint the ACT III discussion together with CERTH. The plan was to streamline developments in Greece and bring it up to speed using ECO-BASE developments.

Preliminary conversation was also held with Danish Technical University. DTU showed interest to contribute with fluid flow and capture research experience.

An ACT III proposal structure and outline were prepared and discussed. After several meetings of the extended consortia it was decided not to pursue ACT III opportunity mainly due to the two main factors:

1. Financing structure (limited budgets are available in Turkey and Romania where the main work would have to be done) and focus of countries involved in potential proposal.
2. More maturation is needed in aligning ideas with industrial stakeholders.

EU green fund and horizon Europe possibilities are currently being studied by the consortia.

Deviations from proposed work plan

During the ECO-BASE project meeting in 2019 the team together with ACT representatives discussed need to restructure SP2 deliverables to better reflect project developments and data availability. The focus of the SP2 shifted from being deeply focused on the subsurface aspects to evaluating techno-economic performance of the whole value chain on the field's operator business case perspective. The new deliverable plan also was subject to delays mainly due to challenges posed by Corona crisis.

SUB PROJECT 3. Knowledge transfer

The sub-project is aiming at knowledge sharing between North-West Europe (NWE) and South-East Europe (SEE).

Meetings organised by ECO-BASE

The Kick-off meeting was held on 11 October 2017 in Athens. Several topics including the status of the data for the first report, database framework, CO_2-EOR workshop in the upcoming Sardinia summer school, and templates, logos, website, publication rules were discussed. The next internal project meeting was held in Utrecht, the Netherland in 2018. The results of the Sub-project 1 has been shared and the potential clusters for Turkey and Romania were presented during the meeting. The roadmap framework was discussed as well, so that the future work has been planned. The meeting was beneficial for programming the work for other subprojects. It was also decided to establish a video meeting every second Tuesday of each month in order to track all project activities. Besides, a weekly Friday status update meeting was held throughout 2019 to coordinate SP2 studies. On 20 June and 19 September 2019, two meeting were held in Bucharest, Romania. The first meeting was about the Romanian case study and the search for a methodology we need to overcome the data scarcity. The next meeting was the annual project meeting and current project status was shared. A new structure for the SP2 deliverables has been constructed during the meeting. The progress on the SP3 and SP4 are also discussed. In order to accelerate the SP2 studies, a two days long meeting was held in Utrecht, the Netherland on 19 and 20 November 2019. The workshop was very helpful on speeding up the simulation cases and aligning the activities in Turkey and Romania. Although the final internal meeting had to be done as an online meeting on 26 November 2020 because of the Covid-19 conditions, it allowed more participation of scientists from each partner. The results of the project have been shared. Project finalization activities were planned.

Dissemination and outreach

The website has been created after the selection of the logo and the colours in the Kick-off meeting (https://ECO-BASE-project.eu/). The website presents the project, the consortium, highlights and newsletters. The Highlights section presented the important events throughout the project. The registrations for the upcoming events were taken and the survey links are also published using the website.

The Newsletters' were prepared to present the latest results and developments of the ECO-BASE project to the broader audience. The first Newsletter presented the ECO-BASE project and the ERA-NET ACT Scheme. The Sulcis Summer School and Dr Sava's interview were included as well. The second Newsletter gave information about the SP-1 cases for both Romania and Turkey. The established framework for Regional EORStore Roadmaps was the second main topic in that newsletter. There were announcements for the upcoming CCUS related events as well. The third Newsletter shared the workshop activities of the ECO-BASE team during the Sulcis Summer School.

The Methodology to optimize for CO_2-EOR combined with permanent storage was also presented. The third newsletter included an announcement for the ECO-BASE Seminar on Legal and Regulatory Framework of CO_2 Utilization and Geological Storage. The fourth newsletter showed the results of that seminar and some announcements about the upcoming events. The fifth and last Newsletter published the results of the ECO-BASE project.

Several key dissemination events were held already during the first project year. Dr Constantin-Stefan Sava (GeoEcoMar) has been interviewed by the Energy Industry Review Magazine. The ECO-BASE project has been presented during the Business opportunities for CCUS in the Baltics (BASRECCS) conference by Roman Berenblyum (NORCE). An extended abstract was submitted and presented as a poster during 14th International Conference on Greenhouse Gas Control Technologies conference. Filip Neele (TNO) presented a paper during the International Energy Agency (IEA) and the King Abdullah Petroleum Studies and Research Center (KAPSARC) workshop on January 2018. Dr Constantin Sava (GeoEcoMar) presented the ECO-BASE project during the 2018 South Eastern Europe Upstream annual conference and exhibition. The dissemination actions for the year 2019 included the open Seminar on Legal and Regulatory Framework of CO_2 Utilization and Geological Storage which was held in Romania on September. The project poster presented at CO_2GeoNet Open Forum on May 2019. ECO-BASE project was presented to Turkish stakeholders by Dr Caglar Sinayuc (METU-PAL) during the events held due to the “Technical Assistance for Developed Analytical Basis for Formulating Strategies and Actions toward Low Carbon Development” project activities. ECO-BASE team was involved with the workshop in Sotacarbo summer school and presented ECO-BASE project status and findings. ECO-BASE project was represented by Christian Bos (TNO) during the EU CCS Storage Research Projects Science-Policy Showcase in Brussels. Dr Alexandra Dudu (GeoEcoMar) presented the ECO-BASE project at the World Petroleum Congress in Bucharest. ECO-BASE was represented by Roman Berenblyum (NORCE) both in the ACT knowledge sharing workshop in Athens and the Zero Emission Platform Advisory Council Meeting in Brussels in 2019. In 2020 very few dissemination events were carried out due to COVID-19 crisis. The key being CO_2-EOR online summer school by METU and project presentation during Bergen winter seminar. The 15th of the Green House Gas Control Conference was decided to be held as a full virtual event and ECO-BASE project outcomes will be presented in March 2021.

Courses

During the Sixth Annual International Sulcis CCUS Summer School (2018), ECO-BASE team has given several lectures to the students about the CO_2-EOR in combination with storage (Roman Berenblyum, NORCE), CO_2-EOR in Turkey (Caglar Sinayuc, METU-PAL) and Romania (Constantin Sava, GeoEcoMar). Then, the students were given a map of Romania and asked for matching emitters and potential sinks by considering the available conditions. Outcomes of the clustering exercise and key factors considered were presented and discussed by the groups.

The Seventh Sulcis Summer School was focused on the CCUS and Low Carbon Technologies in 2019. Around 20 PhD students attended the school. Roman Berenblyum (NORCE), Alexandra Dudu (GeoEcoMar), Caglar Sinayuc (METU-PAL) and Christian Bos (TNO) gave lectures about CO_2-EOR and status of the ECO-BASE project. The students were divided into groups and asked to represent different stakeholders (public, emissions, transport and storage operators) in early dialog on establishing regional business cases, see Figure 14.

Figure 14. Students divided into stakeholder groups.

For the 2020, two courses were planned: the CO_2-EOR Summer School in Turkey and Sulcis Summer School in Italy. Due to the Covid-19, the Sulcis Summer School was cancelled. The CO_2-EOR Summer School on the other hand, was held as an online workshop in September 2020. The students were asked to register via the ECO-BASE website. A total of 121 people mostly students from METU Ankara and North Cyprus Campuses registered the event. The summer school topics included the Enhanced Oil Recovery (Dr Doruk Alp, METU), CO_2-EOR Project in Bati Raman (Turgay Inceisci, Turkish Petroleum), CO_2 Capture and Utilization Technologies (Dr Selcen Basar, Turkish Refineries), CO_2 Pricing and Carbon Policy (Dr Volkan Orhan Tekin, Turkish Refineries) and What is CCUS? Creating a Business Case (Roman Berenblyum, NORCE).

SUB PROJECT 4. Public awareness and acceptance

Public acceptance analysis

In a well-functioning society, decisions are made to solve problems and in order to do so a common understanding is required. SP4 looked at the questions of like: When shaping the public opinion, what role do the editorial and social media play in shaping public perception and opinion? What are the new ways of our time and do trust and mistrust affect democratic developments and the capability to solve common problems? How can we measure developments over time, and how can we evaluate how e.g. ECO-BASE can contribute to media – and thereby public opinion?

Public awareness study

In the spring – summer of 2020 a questionnaire dedicated to the public opinion in Romania and Turkey was launched on the project website. The aim of the research was to understand the level of knowledge and information of the general public about the devastating aspects generated by climate change and the importance of implementing CCUS technology. With 98 people answered, majority were at least informed on the climate change issues, see Figure 15.

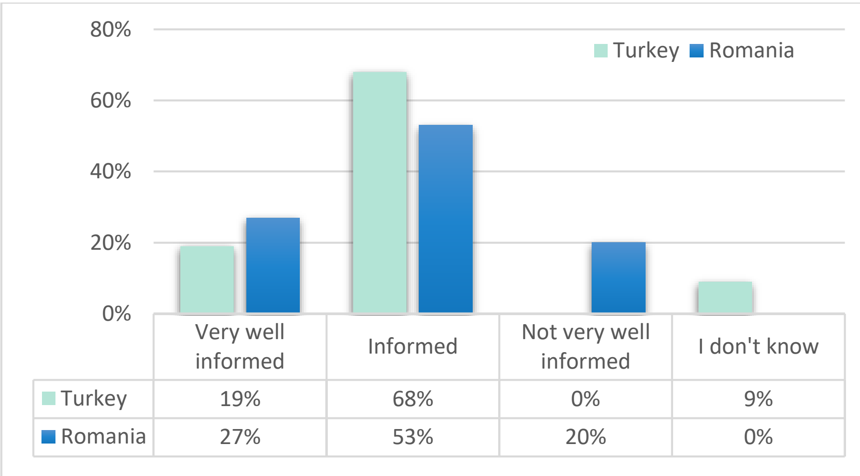


Figure 15. Responses to "How well are you informed about the various cases of climate change?

Reduction of CO_2 emissions were mentioned as the priority by majority in Romania (80% of answers) and about a half of responders in Turkey (48% of answers). 38% of people know what CCUS is, and an additional 22% have at least heard about it. As an outcome of the study we see the need for additional education campaign as a part of further cluster developments, however we do not expect significant resistance to establishing the clusters as they are in the areas generally familiar with industrial operations. In Turkey the cluster would be built on top of existing CO_2 infrastructure and operations.

Liasing with other projects

The projects representatives have been participating at the joint telcons with social scientist from ENOS, ALIGN CCUS, ACORN, ELEGANGY, STATEGY CCUS and PERCEPTION projects. Each project periodically presented results and challenges within the project; there were exchanges of ideas; questions and answer sessions. The initiative taken by ALIGN project to coordinate such meetings proved to be very useful for everyone involved. Social science research is vital in reducing nontechnical risk for CCUS implementation, e.g. by providing insights in narratives, arguments and visuals used in the media, relevant stakeholders and their perceptions, and determinants of public opinion – this will help in making site selection decisions and developing effective public engagement strategies.

Deviations from proposed work plan

After several project meetings ECO-BASE consortia identified need for modification of WP4 deliverables. The changes were presented and discussed with ACT consortia. The idea to merge outstanding WP4 deliverables into one was accepted. The proposed new deliverable will finalize SP4 activities. It will present the workflow for public involvement (earlier D4.1) coordinated with roadmaps in D2.3. The workflow will be built on questionnaire and local awareness analysis (earlier D4.8), outcomes of coordination with other ACT project and stakeholders meetings in March / April (earlier D4.5).

Project impact

The ECO-BASE project addressed the ACT calls thematic area of 'Utilisation'. The ECO-BASE consortium represented a wide range of participants covering research, private and NGO sectors. The project contributed to CCS knowledge transfer across Europe from Norway and Nederland to Turkey and Romania. At the same time the practical experience with ongoing CO_2-EOR projects in these countries and a real potential to expand utilisation of the CO_2 and combine it with permanent storage could become a turning point for EORStore to pave its way into the rest of Europe including offshore applications in Northern Europe.

ECO-BASE has taken into account the larger picture of CCUS through CO_2-EOR, not only by mining data, pairing emitters and sinks, but also by investigating field clusters and setting up a framework for roadmaps and a sophisticated and traceable way to rank CO_2-EOR potential.

A contact with potential stakeholders was established and an interest from oil and gas, energy, refinery and cement producing company was registered. The first draft of the next project application was made by the ECO-BASE team together with stakeholders and additional research partners from Greece and Denmark. The team is currently looking at financing possibilities in EU Innovation Fund or Horizon Europe.

Collaboration and coordination within the Consortium

Regular online meetings of the whole consortium to coordinate progress of the project were set up. The SP and WP teams had more regular meeting (for example weekly meetings of SP2 teams during the main activity period). In general, the scheme is quite effective.

The ECO-BASE project has profited through the transnational cooperation of its participants. The key cooperative added values have been:

- Exchanging the local knowledge and experience across project partners has created regional momentum and lowered the hurdle for implementation of CCUS through CO_2-EOR as a revenue stream for safe and reliable storage.
- Educating scientists and engineers via summer school and courses has broadened everyone's minds and has shown global perspective for CCUS.
- Feedback and support from ACT Consortium
- Positive experience of face to face meetings and knowledge and experience sharing

Project reporting system and requirements set up by ACT consortia allowed for low level of bureaucracy and maximisation of project resources dedicated to actual project work. Decentralized national budget reduce the reporting and money transfer load on the project coordinator, however it removes the management mechanism to redistribute budgets in case of underperforming or faulted partner.

Dissemination activities

During the project duration team members participated in a number of scientific and project events promoting the project in particular and CCUS in general.

4 newsletters were published and distributed to the public. The last 5th newsletter is being released at the same time with this report. The project website was established and updated with the events that took place during the project. In addition, the project partners had the responsibility to promote the project on their own websites and to dedicate space for its description in detail.

On 30 January 2018, AT Paris, France - Frank Wilschut and Phillip Neele presented the project during the IEA – KASPSARC Expert workshop CO_2-EOR

In April 2018 at SEE 2018 Upstream Annual Conference & Exhibition Offshore and Onshore Technology in the Black Sea Region, Dr. Constantin Sava presented ECO-BASE mentioning the most important aspects of the project.

In May 2018, in a comprehensive magazine called Energy Industry Review. ECO-BASE was extensively presented by Dr. Constantin Sava, Senior Geoscientist at GeoEcoMar, in an interview called *Carbon Capture and Storage - Impact, benefits and challenges.* The interview can be read at the following link: https://energyindustryreview.com/interview/dr-constantin-stefan-sava-carbon-capture-and-storage-impact-benefits-and-challenges/

Sixth edition of the International Sulcis Summer School on CCUS Technologies was held between 18 and 22 June 2018. Organized by ENEA, Sotacarbo, University of Cagliari in cooperation with IEA CCC, CO_2GeoNet, and ECO-BASE. 40 students from all over the world met at Sotacarbo Research Center of Carbonia (CI) get a broader view of all the possible issues that revolve around a theme of urgent relevance today, such as the reduction of carbon dioxide emissions into the atmosphere. Summer school also provided information and documentation on all the technological sides of the CCUS subject, including an update of ongoing projects worldwide. ECO-BASE held a workshop about CO_2 Enhanced Oil Recovery where students gather around to establish a business case using the maps and obtained information during the school.

Project and early results were presented in November 2018 in Melbourne, Australia during GHGT- 14 Conference.

In December 2018 in Abu Dhabi, at a conference organized by Carbon Sequestration Leadership Forum (CSLF) Dr Constantin Sava presented the ECO-BASE project.

In April 2019 Energy Industry Review published an article called Prospects for strengthening CCUS implementation in Romania written by Dr Sava Constantin (GeoEcoMar).

ECO-BASE continued to support the summer school in 2019, organised in Carbonia, at Sotacarbo Research Centre by organising the second CO_2-EOR workshop for the students.

In September 2019 an open two-day workshop on legal and regulatory framework was held in Bucharest, Romania. The seminar emphasized on legal, institutional and political frameworks at local, national and international level and how, why and under what conditions these (could) act as barriers or as enabling elements. Different stakeholders from Romania as well as international experts from the Netherlands, Norway, USA, Greece were present at the event. The workshop was announced in Energy Industry Review and on the project website, for registration.

In September 2019 Christian Bos (TNO) presented at Bruxelles - *'EORstore' as CCS market enabler* at the STEMM-CCS Science-Policy showcase event**.**

Dr. Alexandra Dudu (GeoEcoMar) presented the project at the World Petroleum Council organised in Bucharest in October 2019 and some results from the project in July 2020 at the 20th International Multidisciplinary Scientific GeoConference SGEM 2020.

In December 2019 the project outcomes were presented by R. Berenblyum during the ZEP Advisory Council meeting in Brussels.

On 16 September 2020, METU PAL organised CO_2 – EOR Summer School: *ECO-BASE: Establishing* CO_2 *enhanced Oil recovery Business Advantages in South Eastern Europe.* Dr. Çağlar Sınayuç (METU-PAL) as well as other experts from Turkey were present at the event. The coordinator of the project, Dr Roman Berenblyum presented *„CCUS business case establishment.* CO_2 *EOR and* CO_2 *storage"* on the occasion of this meeting.

The project was also promoted during the BASRECCS forum (https://bcforum.net/forum.php) presentation by Roman Berenblyum in his presentation in October 2020.

Project outcomes were presented by Roman Berenblyum during Bergen CCUS 2020 webinar held online on 11.12.2020.

An abstract "CO_2-EOR business opportunities in Romania and Turkey" has been accepted to 15th International Conference on Greenhouse Gas Control Technologies GHGT-15.

The project is also referred to in "CO_2EOR as a pathway to create a CCS infrastructure" abstract also accepted to 15th International Conference on Greenhouse Gas Control Technologies GHGT-15.

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