**Scientific Report 2024**

Project Code: **COFUND-CETP-RamonCO-2**, Name of the Program from PN III:

**European and International Cooperation - Under Program 5.8.1 - Horizon EUROPE**

Project Acronym: **RamonCO**

Project title: **Risk-based structure for the evaluation of CO2 storage monitoring**

Contract no. 42/2024;

Phase I/2024: **Modelling and analysis of information values for the compliance assessment of $CO_2$(I) storage**

## Project Summary

Rising $CO_2$ emissions and their impact on climate change require innovative solutions to reduce the gas concentration in the atmosphere. Our project focuses on developing advanced methodologies and technologies to support safe storage, efficient and long-term geological capture of carbon dioxide using techniques of multi-physics inversion and dynamic monitoring.

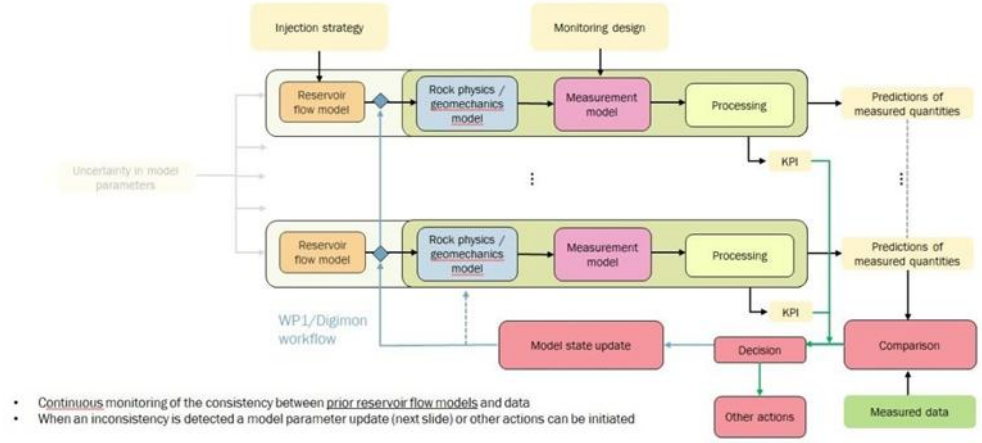


**FIGURE 1 The flow of activities within WP 1**

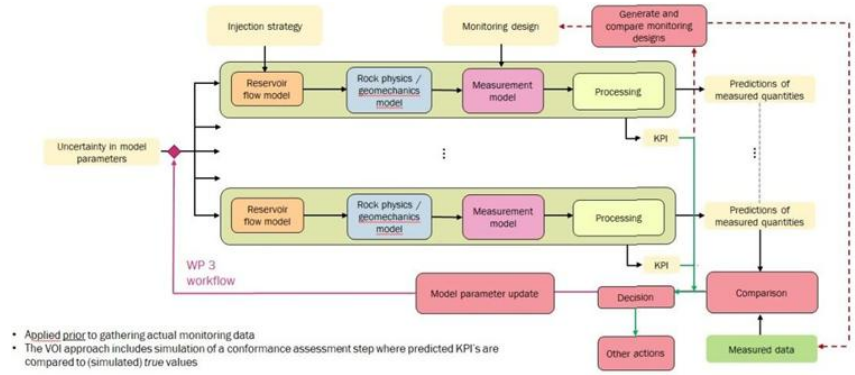


**FIGURE: 2 The flow of activities within WP 3**

The GeoEcoMar team is involved in carrying out activities in **WP1** (Direct Modeling and Inversion of Multi-Physics Data) and **WP3** (Value of Information Analysis for $CO_2$ Storage Compliance Assessment-Figure 1 and Figure2).

## Multi-physical inversion framework: Innovation in basement characterization

The multi-physics inversion framework is an advanced scientific approach that integrates data from multiple sources (seismic, gravity, deformation and thermodynamic) to create detailed models of the basement. This technique provides a robust solution for characterizing storage sites and reduces associated uncertainties:

- **Multi-fidelity data integration**: Using data with varying resolutions such as high-fidelity seismic and lower-resolution gravity data, the usefulness of each source of information is maximized. This integration allows detailed characterization ofregions of interest and provide valuable regional insights.
- **Key advantages**: Increasing the accuracy by reducing the uncertainties, reaching computational efficiency by optimizing the use of data and flexibility in the integration of various sources.
- **Optimized workflows**: The collected data is merged with the help of advanced algorithms and the resulting models are validated and adjusted to ensure their compliance with field observations or synthetic scenarios.

### Validation of methodologies on synthetic cases

To test and demonstrate the performance of the developed framework, complex synthetic cases were used to simulate real $CO_2$ storage conditions. These cases include geological models with realistic geometry and stratigraphy, but also scenarios that analyze migration and behavior dynamics of $CO_2$.

By achieving the project's objectives, the report contributes to the development of a scalable and robust framework capable of supporting the safe and efficient implementation of geological $CO_2$ storage projects. This will ensure not only compliance with environmental standards and existing regulations but also the optimization of monitoring strategies and the reduction of uncertainties related to the behavior of potential storage sites (Figure 3).

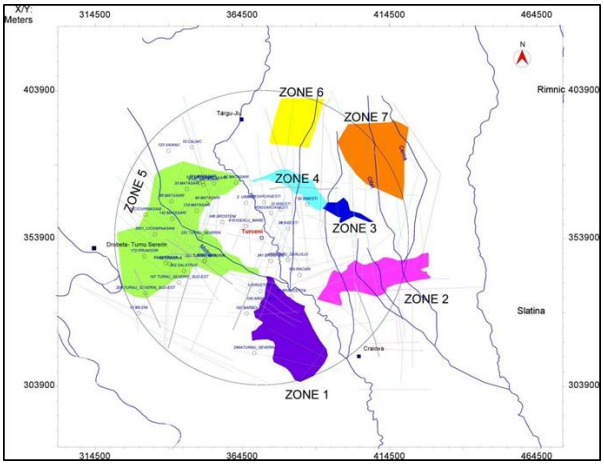


**FIGURE 3 Areas of perspective for the geological storage of CO2 in Oltenia, of which the test case for Ramonco project will be selected**

- **The results achieved**:
  - The capacity of methodologies to accurately predict the behavior of the fluid injected into the basement;
  - Reducing uncertainties and increasing confidence in the validity of models;
  - Robust demonstration of the method stability, even under conditions of incomplete or erroneous data.
- **The impact of the achieved results**: The project provides a validated tool that can be successfully used with in real geological storage projects, thus contributing to safer, more informed and secure decisions.

**Technology expansion and scaling**

To meet the requirements of large and complex projects, the methodology has been extended and optimized to process large volumes of data and to manage various operational conditions:

- **High Performance Computing Platforms (HPC)**: Algorithms are parallelized to run on HPC platforms, reducing the processing time and providing fast access to detailed information;
- **Distributed Processing**: Data is divided into segments, allowing simultaneous processing and the reduction of computational costs;
- **Error management**: The framework includes probabilistic models to minimize

the impact of errors in the initial data on the final results.

**The dynamic model chain for conformity assessment**

An essential aspect of the project is the assessment of geological storage compliance, carried out by dynamic model chains that integrate fluid dynamics, geomechanics and rock-fluid interactions.

- **Hypothetical storage site design**: Sites are modelled using realistic geologists and physical parameters, including the permeability and porosity of rocks, as well as the possible risks, such as $CO_2$ leaks or flake reactivation;
- **Probabilistic simulations**: The Monte Carlo method is used to asess the variations parameters and to generate probable distributions indicating the level of safety and associated risks;
- **Risk visualization**: The results are presented in the form of maps and diagrams, allowing an intuitive interpretation of safety and risks.

**Model update procedure**

In a dynamic environment, the models used must be continuously updated to reflect the new data obtained during monitoring.

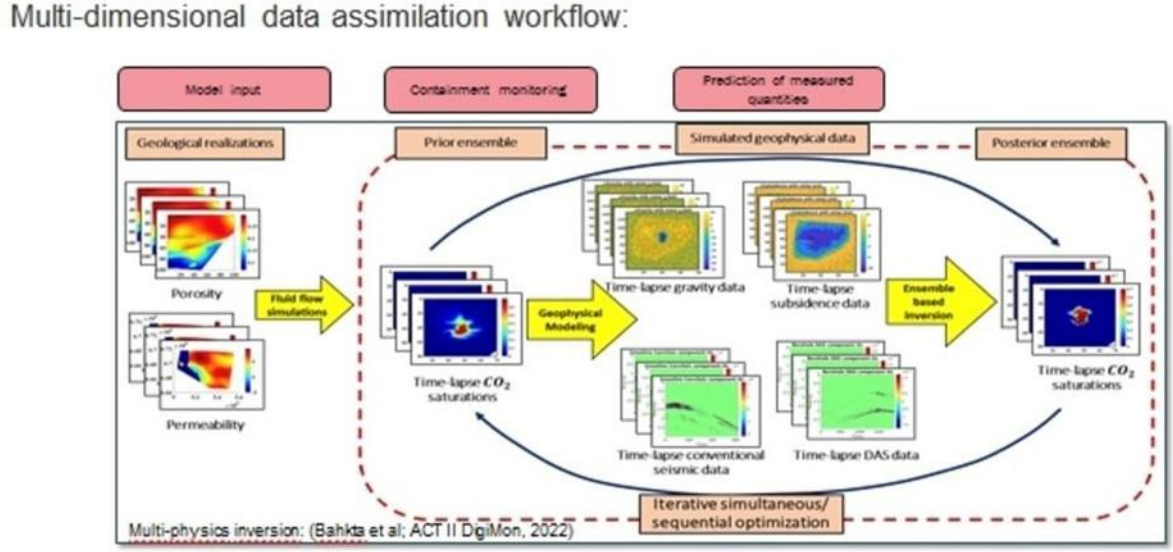


**FIGURE 4 Multiphysics modelling flow**

An advanced multi-physics modeling framework is essential for understanding the complex processes associated with geological $CO_2$ storage. This framework enables the accurate simulation of $CO_2$ dynamics, taking into account physicochemical and mechanical interactions in the subsurface. Its integration into inversion and data processing workflows provides scalability and robustness, contributing to uncertainty reduction and performance optimization (Figure 4).

- **Well-defined workflow:** Collection and processing of new data, parameter adjustment by inversion methods and validation of updated models are made in a continuous flow;
- **Integration of Artificial Intelligence**: Machine learning algorithms such as neuronal networks or Gaussian processes are used to improve efficiency and accuracy of the updates;
- **Data size reduction**: Methods such as the main components decomposition (PCA) ensures fast and accurate processing of large data sets.

**The most significant result of the project**

Successful implementation of an extended and validated multi-physical inversion framework on complex, synthetic cases is the reference achievement of this project. It demonstrates the capability to integrate diverse data and to provide accurate predictions, helping to increase the safety and efficiency of $CO_2$ geological storage projects. By integrating static and dynamic models into a unified framework, a holistic approach to modeling and monitoring geological $CO_2$ storage is ensured. This contributes to a more accurate compliance assessment and reduces uncertainties (Figure. 5).

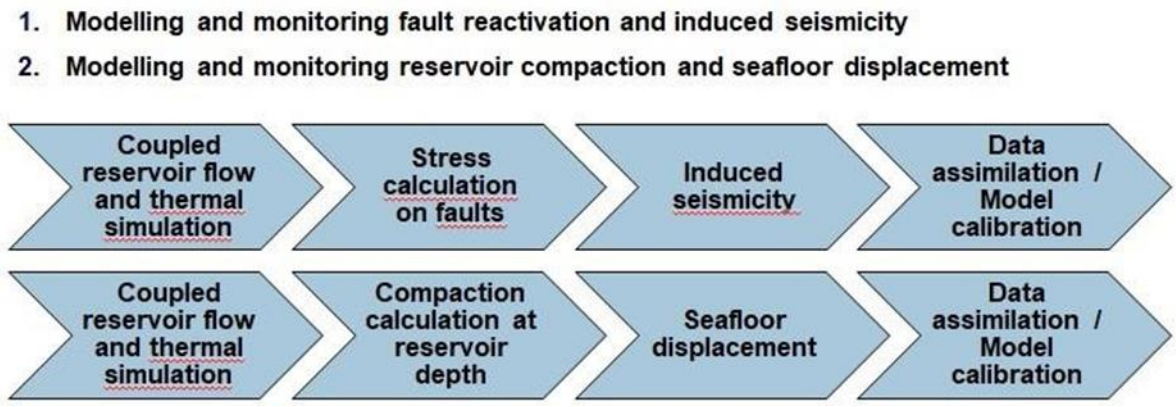


**FIGURE 5 Using geomechanical workflow for risk monitoring in CCS projects**

**Overall impact of the project**

Our project opens new perspectives for the safe and efficient management of $CO_2$ emissions, having a significant positive impact on fighting climate change. By reducing the uncertainties, improving monitoring processes and ensuring storage compliance, the project supports informed decisions and the large-scale implementation of geological storage as a viable solution in the energy transition. Evaluarea valorii informației (VoI-figure.6) presupune cuantificarea impactului colectării și integrării diferitelor tipuri de date asupra îmbunătățirii predicțiilor și luării deciziilor.

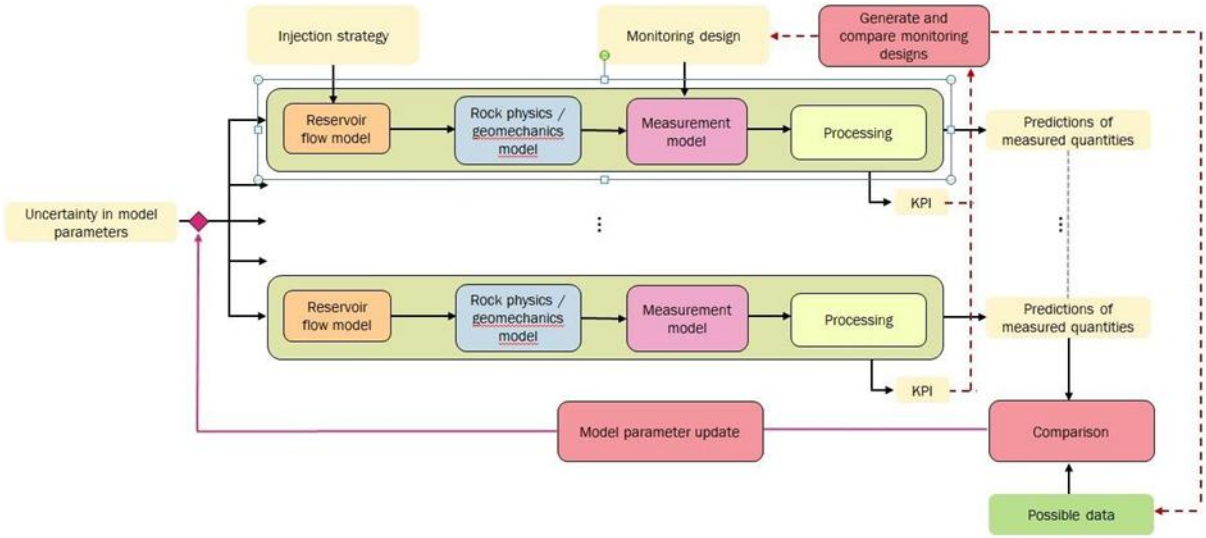


**FIGURE 6 The value of information in practice (VoI)**

This summary gives a brief overview of the project's objectives and achievements, highlighting its contribution to develop advanced $CO_2$ storage technologies with practical applications for a more sustainable, advanced world.

Project Manager

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