# BOOK PRESENTATION

The global warming theory indicates that the global mean surface air temperature has increased during the last 200 years. This surface air warming is responsible for a worldwide phenomenon known as Climate Change. At its highest incidences of extreme climate events, it is modifying the rainfall regimes and, consequently, directly affecting our everyday life on the planet. The main cause of global warming is the increase of total greenhouse gas (GHG) concentrations in the atmosphere, where the carbon dioxide ($CO_2$) produced from anthropic activities is the primary contributor.

In this regard, the United Nations (UN), through various international agreements, recognised the need for urgent actions to address the effects of climate change. One of these international agreements is the Paris Agreement signed in 2015 by 157 countries, which aims to maintain the global temperature rise at a maximum of 2 °C above pre-industrial levels by decreasing greenhouse gas emissions (UNFCCC, 2015).

Among the available options for $CO_2$ emissions reduction, the technologies known as CCS (Carbon capture and storage) or CCUS (Carbon capture, utilisation and storage) are the most effective technique. CCS or CCUS technologies are considered essential parts of the lowest-cost paths to achieving the targets set during the Paris Agreement (Global CCS Institute, 2019). The

CCS technologies sequestrate carbon from the atmosphere by capturing $CO_2$ at its stationary emission sources and storing it during a long-time period or even permanently in rock formations. Therefore, the application of CCS technologies to the industrial and power generation sectors, the largest $CO_2$ emitters, is not just an option but an obligation to sustain the essential activities of humankind.

The south-eastern region of Brazil is the most industrial carbon-intensive zone of the country. It is one of the leading producers of oil, gas, and biofuels, thus the most greenhouse gas emitter. Therefore, the perception is that this region is the prefered location to apply CCS technologies, especially the $CO_2$ geological storage aspects. Subsequently, it is essential to conduct detailed evaluations to identify the most economically suitable and secure locations to store the captured $CO_2$.

The $CO_2$ geological storage is a compelling option because it allows safe storage for a long time, more than a thousand years, tremendous amounts of $CO_2$ compatible with the current greenhouse gas emissions. According to the IPCC (2005), the reservoir options for $CO_2$ geological storage are depleted oil and gas reservoirs, deep saline aquifers, mined salt caverns, unmineable coal seams, basaltic rocks, and organic-rich rock formations (Bachu, 2000; IPCC, 2005; Busch et al., 2008). All the above-stated options available in the south-eastern region of Brazil, with three of its sedimentary basins – Campos, Santos, and Paraná – already classified by Ketzer et al. (2014) as high prospective basins for CCS application.

Nevertheless, not all the previously commented rock formations are feasible $CO_2$ geological reservoirs. Potential reservoir rocks for $CO_2$ storage must exhibit the required characteristics to sustain large amounts of $CO_2$ injection during a time interval that is compatible with the $CO_2$ emissions and guarantees $CO_2$ reservoir retention for a long time (e. g., more than 1000 years). They should also have the appropriate conditions to avoid $CO_2$ leakage into the surface or nearby water bodies, with traps that confine the $CO_2$ storage reservoir, such as sealing rock formations (e. g., impermeable rock layers) or geological structures.

Specifically, potential reservoir rocks must demonstrate good porosity, permeability and adequate $CO_2$ geochemical trapping mechanisms such as gas sorption into organic matter and clay minerals (especially in coals and shales). Rocks containing Ca, Mg, and Fe (e. g., basalts) react with $CO_2$ to boost $CO_2$ storage because of their carbon mineralisation potentials. The interaction of $CO_2$ with mafic-to-ultramafic basaltic rocks enhances the permanent trapping of $CO_2$ in neoformed minerals.

Reservoir depths requirement for $CO_2$ storage is over 800m at formation pressures of at least 73.9 bar (IPCC, 2005; WRI, 2008; Herzog, 2018). Other factors must be carefully evaluated, including the reservoir $CO_2$ retention capacity, $CO_2$ storage volume, $CO_2$ injection capacity, and operational costs.

The most used method for $CO_2$ geological storage is $CO_2$ reinjection during enhanced oil or gas recovery operations in producing fields. The Pre-Salt offshore operations of the Santos sedimentary basin uses this method. Other efficient methods are the $CO_2$ injection in coal seams to enhance coalbed methane recovery and organic-rich black shales to enhance gas recovery. Paraná basin contains all the $CO_2$ geological storage options, such as basaltic rocks, coal seams, organic-rich black shales, saline aquifers, sandstones, and typical oil and gas reservoir-type rocks. It is also the largest onshore sedimentary Basin with a superficial area of 1,500,000 km2, including its extension to Paraguay, Argentina, and Uruguay (Milani et al., 2007). The Parana basin spreads across the carbon-intensive region of the country. Therefore, considering the locations, dimensions, geological settings, and reservoir stimulation suitability, Paraná and Santos sedimentary basins are the most favourable environments for $CO_2$ deep geological storage. In addition, considering that the CCS technologies are relatively new, the regulatory, legal, and environmental aspects must also be appropriately addressed and in full compliance with the planning and development of the CCS technologies during all stages of the future projects in the south-eastern region of Brazil.

Therefore, the book reflects the results of all the research studies developed during Project 36 (Perspectives for Carbon storage in onshore non-conventional oil reservoirs and offshore sedimentary basins in Southeast Brazil) of the Research Centre for Gas Innovation (RCGI) located at the Polytechnic School of the University of São Paulo and financed by SHELL and FAPESP. The chapters intend to discuss the topics related to the technologies involving $CO_2$ geological storage. Furthermore, they present the theoretical concepts and findings of the studies that preferentially focused on the organic-rich black shales of the Irati Formation, which is considered a potential geological unit for unconventional oil and gas reservoirs equivalent to those named in the United States of America. Overall, the book chapters present readers with a clear vision of the CCS-related techniques and the techno-economic potential of the $CO_2$ geological storage to mitigate greenhouse gas emissions in the southern-eastern region of Brazil.

Furthermore, the book presents the latest studies of the CNPq Research Group (Estudos para Armazenamento Geológico de Carbono - CCS) from the Institute of Energy and Environment (IEE) of the University of Sao Paulo. The results of the Research Group served as crucial findings for project 36 of the Research Center for Gas Innovation (RCGI) regarding the technical and regulatory issues for the implementation of Carbon, Capture and Storage (CCS) technologies, especially $CO_2$ geological storage in the Southeastern Region of Brazil, in the Paraná and Santos Basins. It provides an overview of the potential for secured long-term storage of $CO_2$ in south-eastern Brazil. The book also presents the academic findings related to $CO_2$ reservoir properties and criteria for selecting the best sites for $CO_2$ storage while looking to improve the decision-making process of the Brazilian CCUS development and contribute to the R&D (Research and Development) plan concerning greenhouse gas emissions mitigation.

The book focuses on the complete assessment of two of the most favourable locations within the prospective basins in Brazil, Paraná and Santos basins. The methodological approach involves geological evaluations and regulatory analyses. The geological aspect includes benchmarking, geochemical analyses, 3D modelling, petrophysical modelling, and statistical data analyses to characterise the $CO_2$ geological storage potential. It also includes numerical reservoir simulations for the calculation of $CO_2$ reservoir capacity. Meanwhile, the regulatory investigation consists of a descriptive method adopted to represent the state of the art stationary sources of $CO_2$ emissions in the southeast region of Brazil. The methodology to regulatory contents for the best practices exposition include:

1) analytical and deductive method;
2) systematic and teleological method;
3) hermeneutics;
4) the comparative method.

The research techniques are documentary and theoretical analysis, as well as institutional actions and composition descriptions. The most critical challenge our primary and secondary audiences face is the lack of geological evaluations, modelling data, and regulatory and legal certainty. Therefore, the book tends to address this challenge by answering the following questions:

a) Where are the most favourable area within prospective locations to implement CCUS projects in Brazil?

b) How to implement feasible CCUS projects in Brazil?

c) What are the required parameters for internal regulatory and legal compliance for feasible CCUS implementation in Brazil?

The novelty lies in directing the content to the non-specialised public to improve the decision-making process for development in south-eastern Brazil with an interdisciplinary assessment of its potential based on integrating geological, engineering, and regulatory checks. Furthermore, the innovation relies on selecting the best sites for both onshore and offshore CCS deployment and fully characterising the most prospective geological formations and their $CO_2$ reservoir capacity.

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