Geological storage of CO2 in depleted reservoirs with lithological modeling and analysis of technical viability

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Abstract. The objective of this work is to understand the key variables dictating the complexity and viability implementation of carbon capture and storage (CCS). This involves examining the mathematical relationship between storage capacity available in a reservoir and the various costs associated with injection implementation — Initially considering factors such as the distance from the reservoir to gas pipelines and facilities survey around them —, in other words: Quantify which oil fields have a higher viability for CCS installation. This way, identifying which fields are viable today will allow us to discuss a forecast of which fields will be economically and technically viable in the future, anticipating measures to mitigate CO2 emissions, ensuring a viable, safe and smooth energy transition with powerful, clean and yet reliable energy. The study found that the viability of fields in the Potiguar Basin for Enhanced Oil Recovery (EOR) using CCS is significantly higher than in the Recôncavo Basin due to better injection space. The Guamaré field was identified as the most promising. Limited information on other fields prevented their comprehensive study and validation of trapping mechanisms in this research. Future studies could explore reservoir shape, lithology and CO2 injection dynamics in the Guamaré field.

Keywords: CCS, Viability, Geological modeling, Potiguar Basin.

1 Introduction

Reducing CO2 emissions is critical in the fight against climate change, as elevated atmospheric CO2 levels contribute to global warming, extreme weather events, and ecosystem disruption. Carbon capture and storage (CCS) plays a vital role in this effort significantly cutting emissions from industrial processes and power generation. By capturing CO2 before it enters the atmosphere and securely storing it underground, CCS can help mitigate the impact of fossil fuels while transitioning to cleaner energy sources. While CCS is the most reliable way to reduce CO2 emissions in Earth's atmosphere, a study is still required to determine when and where it is viable [1]. The implementation of CCS presents a complex challenge, with numerous variables impacting its feasibility. In the case of injecting into petroleum reservoirs, for example, we need to consider the 'space' available for gas, the geology of the field to ensure CO2 trapping for the most extended possible period, and the possibility of financial return through enhanced oil recovery (EOR), in addition to various other operational and logistical issues. In this context, geological modeling and numerical simulation are essential for studying CCS as they ensure safety and reliability in geological CO2 storage projects. These methods enhance the understanding of CCS implementation by providing quantitative and qualitative analyses of uncertainties, such as the heterogeneity of the reservoir [2]. Consequently, the groundwork is laid for the next crucial step: Interpolation modeling, leveraging the identified candidates and data to improve efficiency and effectiveness in CCS projects. This modeling process involves integrating geological data, spatial analysis, and computational simulations to develop comprehensive reservoir models. These will enable a more accurate assessment of the storage capacity, injectivity, and long-term behavior of CO2 within the selected most viable reservoirs for CCS. By understanding the subsurface dynamics and potential risks associated with CCS, this study aims to provide valuable insights for optimizing injection strategies, mitigating potential environmental impacts.

In this way, the current work aims to determine the key factors influencing CCS viability in petroleum reservoirs, focusing on the relationship between reservoir storage capacity and injection costs. This research will identify the most promising candidates for CCS projects by analyzing geological and production data from mature oil fields. Understanding is essential not only for developing effective CCS strategies but also for meeting global climate goals and ensuring a sustainable energy future accompanied by technical and economic viability that ensures a safe and smooth energy transition.

2 Methodology

2.1 Data mining

The study targeted the potential of two Brazilian basins with carbon capture and storage (CCS): The Potiguar and Recôncavo basins. These basins were chosen due to several factors, including their large reservoir extension, production age, and the availability of extensive geological information. Historically, two of the main hydrocarbon reservoirs explored in the basin stand out as two of the largest onshore producers in Brazil. The growing interest in revitalizing mature fields with CO2 was also a reason [3].

The initial stage of the work involved collecting relevant data. This data mining process utilized sources from the National Petroleum Agency (ANP) and ANP TERRESTRE, Specific criteria were established to select suitable fields for further analysis. A minimum production time of 30 years was required, indicating that the field was depleted. Fields with shorter production times were excluded from the study list. Additionally, fields with lack of geological information were also removed from consideration.

Following the data collection and filtering process, 104 fields were identified and distributed between the Potiguar and Recôncavo basins. These fields will undergo feasibility studies to assess their suitability for CCS implementation. The collected information encompasses a wide range of parameters, including Field extension (in km^2): The spatial extent of the field, reservoir, and trap formation, porosity, permeability, volume of oil and gas produced, coordinates, and other production and lithology data. The comprehensive dataset collected will be used to evaluate the technical feasibility and potential of these fields for CCS, contributing to developing strategies for carbon mitigation in Brazil.

2.2 Viability Equation

After bibliographic studies from IEA (Internacional Energy Agency) and IEAGHG (IEA Greenhouse Gas R&D Programme) and considerations about what would be more viable and important to consider in a first analysis, we arrived at the following feasibility equation:

$$Feasibility = \frac{(FPO\ x\ OOIP)\ +\ (FPG\ x\ OGIP)}{Pipeline\ distance\ (in\ meters)} \tag{1}$$

This is a relationship between the available space for CO2 injection in the reservoir and the licensing and production costs of pipelines transporting this CO2, where: FPO is the fraction of oil produced. FPG is the fraction of gas produced. OOIP is the original oil in place (in millions of m^3) and OGIP is the original gas in place (in millions of m^3). Viability is given in terms of "storage/distance", indicating the CO2 storage capacity in relation to the transportation distance. This metric allows for the evaluation of the project's cost-effectiveness, considering both the reservoir's storage potential and the logistical challenges of CO2 transportation. For better visualization, was done the georeferencing of fields and pipelines using the QGIS software, and taking advantage of the need for georeferencing to estimate the distance of the pipelines, we made a bubble chart of the feasibility (Fig. 2) according to equation (1).

2.4 Modeling

We used the Python libraries: “Scipy” and “VTK” to generate points based on the depth and geological information of the wells, which were obtained from “ANP terrestre” through composite profiles, requiring analysis of gamma-ray , density and other logging data to estimate the top and base of the reservoir (Fig. 1). This way, information points (the wells) were obtained and then interpolated. So, now we have the shape of the reservoir.

3 Results and Discussions

The requirements considered when injecting CO2 in reservoirs is diverse and divided into three main categories: Geological; Physical, thermodynamics and hydrodynamics; and techno-economic, social and regulatory. For geological, one must pay attention to porosity, permeability, stability, CO2 sorption (clay minerals and organic matter) and the degree of exploitation of the Basin. For physics criteria: Gas behavior in the reservoir (pressure, bubble an critical point) and its interaction with nearby water bodies. Last, the most studied on this work: The techno-economic, social and regulatory criteria: ranges from project costs to impacts on human life, maintenance and safety in storage. [4]; [5]; [6].

To assess the CO2 storage potential and guarantee the criteria discussed above in the studied basins, data from gamma ray, density, neutron, and resistivity logs from the Guamaré field were used. These data allowed us to understand the rock properties, lithology, and, importantly, to estimate the top and base of the reservoir from the logs. In Fig.1, for example, we have the logs from Well 7-GMR-72-RN. Additionally, they provided information on depth, thickness, and intercalations of layers. These parameters are essential for evaluating the safety and efficiency of CO2 storage.

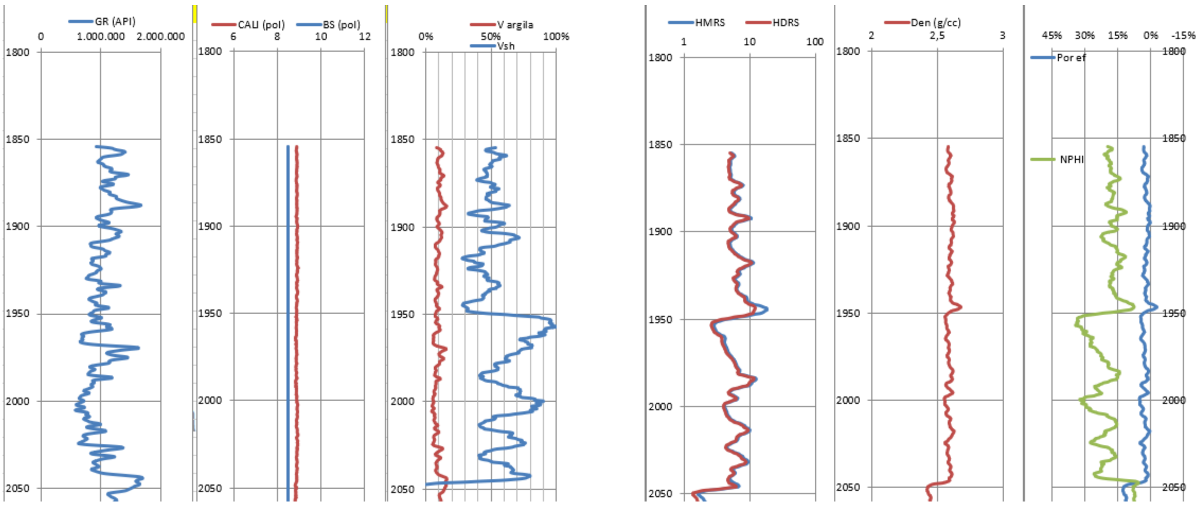


Figure 1. Example of log profiles used to estimate the reservoir’s top and base: Well 7-GMR-72-RN.

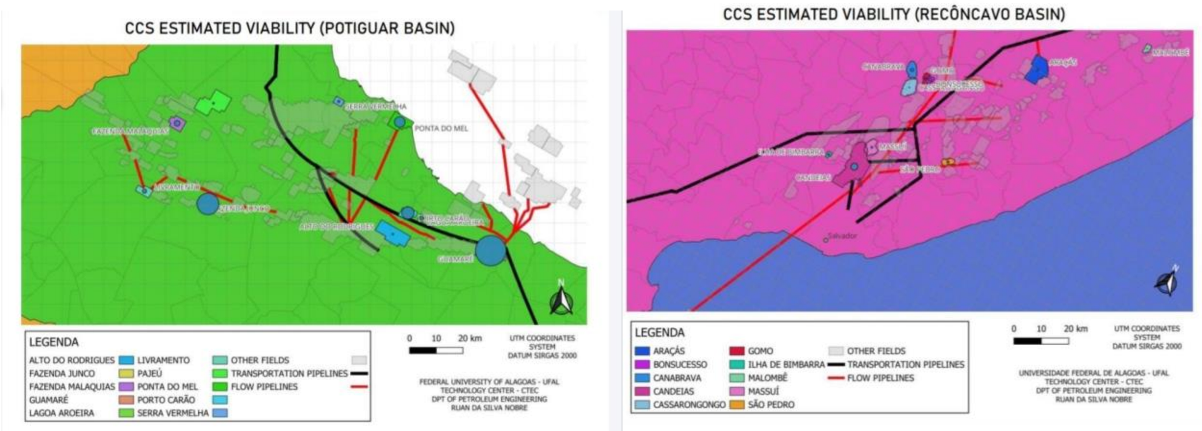
Budinis (2018), states that the cost of CCS has been identified as the major challenge preventing the widespread adoption of this technology. At the moment there is no market for CCS, mainly because a plant with CCS will always be more expensive (in terms of capital and operating costs) than the same plant without CCS. Enhanced oil and gas recovery options represent the only exception and in fact have been employed for many decades. Without effective mechanisms to underpin uptake, the deployment of CCS to a level that would be adequate to meet climate change targets will remain implausible. Steven T. Anderson (2016), Frequently compares and contrasts the findings of different studies like pressure management, geological formations, and trapping mechanisms, emphasizing how these assumptions can significantly influence the estimated storage capacity and costs. That way we can see how the data mining on this work was one of the most important steps.

After defining the equation used, the 20 most viable fields were selected, considering the equation: 10 fields from Potiguar and 10 fields from Recôncavo, in (Tab. 1) we have the 14 most viable fields among all the 104 studied. From those, only the most viable basin (with a minor lack of well data) was chosen for the geological modeling step, this one was the Guamaré field.

Table 1. Most viable fields studied

Field	Basin	Viability Sto/Distance
Guamaré	Potiguar	9,11
Fazenda Junco	Potiguar	4,61
Porto Carão	Potiguar	1,48
Ponta do Mel	Potiguar	1,11
Candeias	Recôncavo	0,43
Fazenda Malaquias	Potiguar	0,30
Livramento	Potiguar	0,16
Lagoa Aroeira	Potiguar	0,13
Canabrava	Recôncavo	0,09
Bonsucesso	Recôncavo	0,07
Serra Vermelha	Potiguar	0,05
São Pedro	Recôncavo	0,04
Araçás	Recôncavo	0,04
Gomo	Recôncavo	0,03

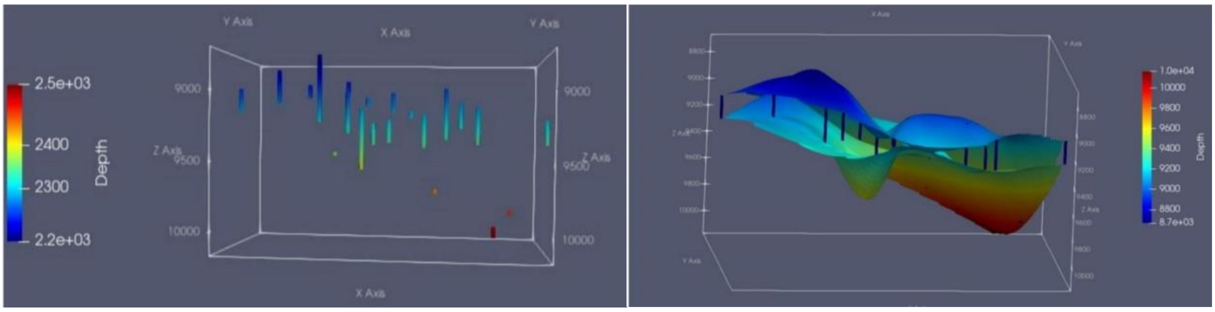
With the values in the table, we can conclude that the Potiguar basin was significantly more viable due to the large amount of oil and gas produced, resulting in ample space for flow and storage of CO2 gas. The gas pipelines have good values, but they are not very different from those found in the Recôncavo basin (Fig2). Svensson (2019) cites numerous sources to discuss the cost implications of uncertainty in CO2 storage resource estimates. A possible way to quantify the viability variation due to CO2 transport is, as done in Anderson (2016) A module-based cost and capacity analysis, which gives the capacity and overall transportation cost per ton of CO2 for various distances for each means of transportation investigated with various types of pipelines.



(a) (b)

Figure 2. Georeferenced maps from Potiguar (a) and Recôncavo (b) basins, with pipelines and oil fields.

According to Anderson (2016), a possible way to quantify the variation in feasibility due to CO2 transportation is to conduct a study on the implications of uncertainties in CO2 storage resource estimates. Thus, a cost and capacity analysis based on modeling was performed, which provides the capacity and total transportation cost per ton of CO2 for various distances and each transportation mode investigated with different types of pipelines. The use of 3D modeling (Fig. 3), along with well logging data (Fig. 1), allows for an expansion of geological data analyses, contributing to the assessment and correction of uncertainties. Another issue that must be considered is the proximity of these pipelines to residential and populous areas, due to the high corrosion and risk of asphyxiation that leaked CO2 could cause. Thus, it is understood that viability costs are not limited solely to the project implementation cost, but also include the cost of accident prevention and environmental risks. After all, CCS is initially a pro-environmental measure.



(a) (b)

Figure 3. Wells with top and base of the reservoir in GMR field (a) and the shape using interpolation (b)

4 Conclusions

Finally, we obtained satisfactory results regarding the viability of the fields in the Potiguar Basin, with exponentially higher values than in the Recôncavo Basin, mainly due to the available space for injection. Thus, despite the large extent of reservoirs in Recôncavo Basin, applying the EOR technique using CCS today would not be so beneficial. The Guamaré field proved to be the most viable. It is worth noting that other possibly viable fields had little public information, making it impossible to study and prove the trapping in this work. Therefore, we can conclude that in the future, when there is more production and consequently more storage space in the Recôncavo basin, we will also see positive viability values in the studied fields. It is important to emphasize that this is preliminary work; more variables will be considered in the viability equation as more information becomes available. Other influencing variables that could not be obtained include the distance and characteristics of the stationary source for gas capture, logistical processes, EOR returns, and technical processes. Furthermore, from the reservoir shape and lithology found in this work, it will be possible to carry out other works involving the Guamaré field and the injection of CO2 in it, such as: studies of bubble formation and critical point of CO2 in closed reservoirs.

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