CHAPTER 2

CO_2 GEOLOGICAL STORAGE IN SANTOS BASIN: POTENTIAL AND BEST SUITABLE SITES

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ABSTRACT

The search for reservoirs is a relevant part of CCS projects, and in the Brazilian context, it is crucial to think about strategic locations associated with stationary CO_2 sources. Thus, the Santos Basin is a region of interest since it contains essential oil and gas reserves like those in the subsalt area. Depleted oil and gas fields appear to be more favourable reservoir options due to local technical studies, infrastructure availability, connections with emission centres by pipelines or ship routes, and fewer environmental risks. This chapter explores the potential and best suitable sites, focusing on the case of the Merluza Field. The presence of infrastructure is another favourable point for choosing the Merluza Field as a location for the geological storage of CO_2. Economically, adaptation to the existing activity tends to be much cheaper than construction with no initial infrastructure available. In the case of Merluza Field, the reservoir structure is open for use. The existing pipeline is also an advantage if the field is selected as the continental CO_2 storage site. The two reservoir possibilities (rocks from the Juréia Formation and Itajaí-Açu, Ilhabela Member) have characteristics favourable to be CO_2 geological reservoirs.

The high porosities, mainly for the Ilhabela Member, indicate that large amounts of gas can be injected.

Keywords: CO_2 geological storage; Depleted hydrocarbon fields; Santos Basin.

1. INTRODUCTION

The global community has authorised the choice of an ambitious greenhouse gas (GHG) reduction target from the Paris Agreement (UNFCCC, 2015; IEA, 2016). The global energy sector has a significant role in this paradigm shift since it accounts for 72% of global GHG emissions (WRI, 2019). Among the various options for mitigating emissions, carbon capture and storage (CCS) has emerged as a relevant tool, especially concerning energy transition (IEA, 2007). The search for geological reservoirs is an integral part of a CO_2 capture and storage project because it corresponds to the final destination of the gas. Thus, it is necessary to find regions that adequately meet the criteria established for a reservoir to retain CO_2 in the long term. Making this analysis depends on compiling various geological data and information associated with infrastructure and local regulation. The Santos Basin (figure 1) has a total area of about 35,2260 km² spreading across Rio de Janeiro, Santa Catarina, São Paulo and Paraná states (FREITAS et al., 2006).

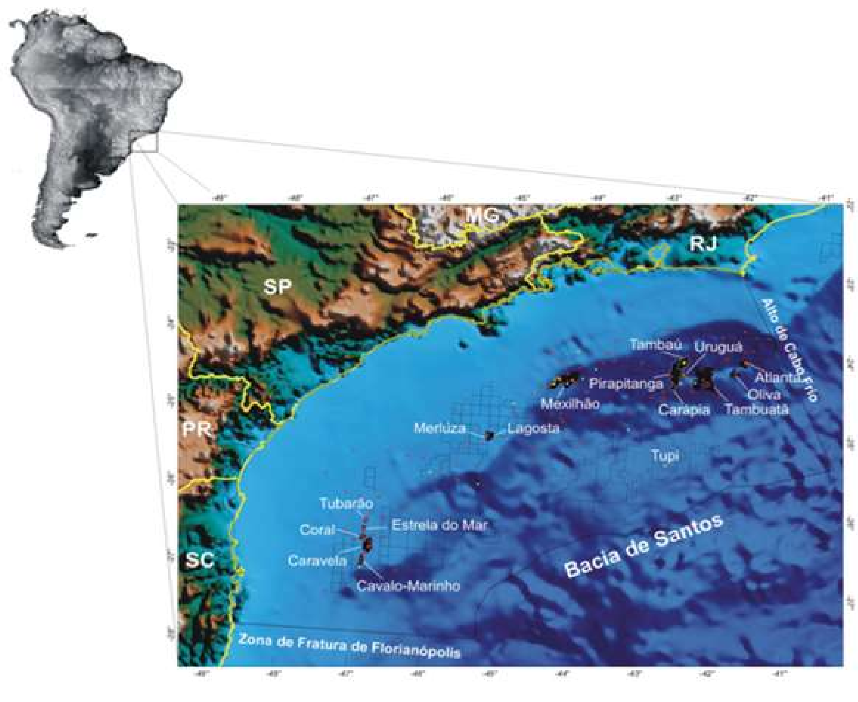

Figure 1. Location of the Santos Basin. Source: Chang (2008).

This work is set in a world scenario of the search for global solutions to climate issues. In this sense, CO_2 capture and geological storage technologies work as possible tools to reduce greenhouse gas (GHG) emissions to achieve the goals proposed in the 2015 Paris Agreement (UNFCCC, 2015). For the national energy planning to consider the geological storage of CO_2 as a GHG abatement tool, studies about the geological feasibility of the Brazilian territory are necessary. The search for regions in the national environment must also consider infrastructure and economic feasibility and cost optimisation. In this sense, the search for reservoirs in the Santos Basin arises naturally due to the Basin's strategic position geographically (located near relevant economic-emitting hubs) and the arrangement of oil fields distributed throughout its area.

Therefore, the scope of this work is to investigate the potential use of the Santos Basin for CO_2 storage. Looking for reservoirs in the Santos Basin means looking at rock formations with suitable geological conditions for CO_2 storage. The site selection criteria are separated into geological, physical and economic-social factors (BACHU, 2000; TOMIĆ et al., 2018). The previous selection of depleted fields is based on their proven higher economics and advantages concerning technical expertise, available infrastructure for adaptation, and lower environmental risks (HANNIS et al., 2017). The Santos Basin has also stood out in activities related to supply infrastructure (figure 2). : There are five refineries installed in its vicinity (REDUC, RPDM, RECAP, REVAP and RPBC) within a distance of up to 80 km from the Basin's limits, with a total daily refining capacity of 119,200 m3 of oil representing approximately 32% of the current national capacity (EPE, 2019).

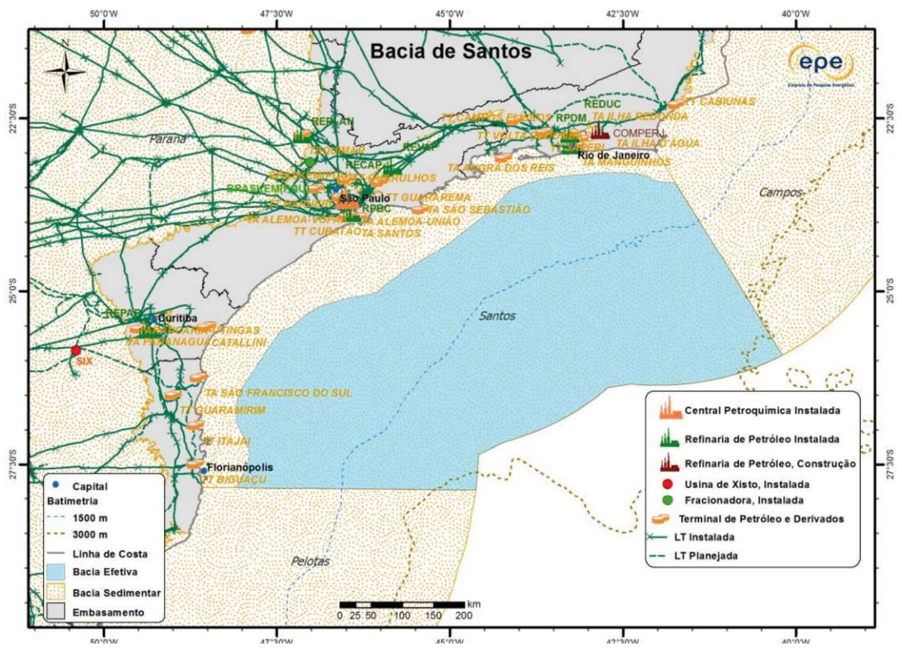

Figure 2. Santos Basin supply infrastructure: refineries, terminals and transmission lines. Source: EPE (2019).

Therefore, this paper presents a general overview of the characteristics of the Santos Basin, which favour its use for carbon storage, considering the Merluza Field as a case study. It hopes to establish the state-of-the-art knowledge of the Santos Basin from the perspective of the geological storage of CO_2.

2. METHODOLOGY

The methodology (figure 3) of this work consists of a critical literature review and the indication of the most appropriate units to store CO_2 in the Santos Basin based on the selected data. The outline of the methodology is as follow; i: data collection, a bibliographic survey on the Santos Basin geology and infrastructure, ii. Data analysis based on the bibliographic survey on CCS and selection criteria for CO_2 storage, and iii) Mapping of results: definition of the desirable characteristics for a rock to act as a reservoir.

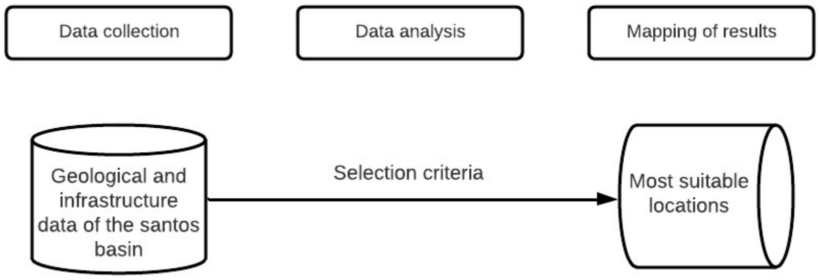

Figure 3. Methodology layout.

3. RESULTS AND DISCUSSION

The results of this work aided to define the storage site selection criteria, CO_2 storage possibilities in the Santos Basin in general terms, and finally, presenting the Merluza Field case study.

3.1. Criteria

Before developing storage technologies, it is necessary to identify critical selection criteria to tell whether the chosen reservoir is environmentally safe, economically suitable and geologically feasible (AMINU et al., 2017). The requirements that should be considered when geological reservoirs for CO_2 storage are diverse and are divided into three main categories (BACHU, 2000; LLAMAS, 2014; TOMIĆ, 2018):

i) geological;

ii) physical, thermodynamic and hydrodynamic;

iii) techno-economic, social and regulatory. When dealing with geological criteria, one must pay attention to porosity, permeability, tectonic stability, reservoir characteristics, CO_2 sorption (clay minerals and organic matter) and the degree of exploitation of the Basin. The physical, thermodynamic and hydrodynamic criteria consider gas behaviour in the reservoir and its relationship with nearby water bodies. Finally, the techno-economic, social and regulatory criteria range from project costs to impacts on human life and regulatory possibilities.

Therefore, the results expressed in this work do not start from a single perspective but the combination of several views for the same problem in the search for the most appropriate regions in the Santos Basin for CO_2 storage.

3.2. Best locations for CO_2 storage in Santos Basin

The offshore location of the Santos basin presents both challenges and benefits for a CCS project. While there is no need to worry about human populations in nearby cities, the marine fauna and flora require attention, and more difficulties in addressing the environment are needed.

Before going into the criteria previously mentioned, it is necessary to look at the entire Basin. The Santos Basin has approximately 352 260 km2 and faces the states of Rio de Janeiro, Santa Catarina, São Paulo and Paraná. It is limited to the north by Alto do Cabo Frio (Campos Basin), to the south by Alto de Florianópolis (Pelotas Basin). The Basin extends to roughly the limit between the continental crust and the oceanic crust to the east, and the Santos Fault limits it to the west (FREITAS et al., 2006).

The origin of the Santos Basin is associated with the opening of the South Atlantic Ocean. There are several possible interpretations for this event, with three main approaches standing out: (1) thermal doming caused by crustal thinning (ASMUS, BAISCH, 1983); (2) lithospheric stretching preceding the opening and placing thermal anomalies as secondary (CHANG et al., 1992); (3) mixed processes depending on the absence or presence of mantle plumes and different stretching rates along the proto-edge (GLADCZENKO et al., 1997). The Santos Basin is due to an anomalous stretching caused by the excessive heat in the area of the São Paulo Plateau by the Tristão da Cunha plume (MACEDO, 1990). The anomaly caused by the Tristan plume may have resulted in a regional uplift associated with the Basin's mechanical subsidence, explaining a rift section with less thickness (ANP, 2003). The rift phase of the Basin would be represented by a mosaic of NS to NE/SW synthetic faults, with antithetic secondary systems, resulting in a series of half-grabens with internal highs (CAINELLI, MOHRIAK, 1998).

The primary geological information and main characteristics of the stratigraphic units are summarised in tables 1 and 2.

Geographical Situation		Sea
Sedimentary Area		308057 km²
Effective Basin Area		240901 km²
Exploratory Maturity		High potential
Main Oil System		Guaratiba - Guaratiba (!)
Exploratory Plays	**Play**	**Main Reservoir**
1	Marambaia (Neogene)	Neogenous turbiditic sandstones - Marambaia Formati
2	Marambaia (Paleogene)	Paleogenous turbiditic sandstones - Marambaia Formation
3	Santos - Jureia	Campanian-Maastrichtian sandstones - Santos Juréia Formation
4	Ilhabela	Lower Coniacian-Santonian turbiditic sandstones - Itajaí-Açu Formation (Ilhabela Member)
5	Camburi	Albo-Cenomanian carbonates - Guarujá Formation
6	Pré Sal Microbialites	Aptian microbialites - Barra Velha Formation
7	Pré Sal Coquinas	Barremian-Aptian coquinas - Itapema Formation
8	Fractured basement	Neocomian fractured basalts - Camboriú Formation

Table 1. Geological information of Santos Basin. Source: adapted from EPE, 2019.

Geological unit	Main features
Camboriú Formation	Basaltic spills below the sedimentary section for almost the entire length of the Basin.
Guaratiba Formation	Pack of clastic and carbonate rocks located above the Camboriú Formation and below the evaporites of the Ariri Formation, with both discordant contacts.
Ariri Formation	They are composed of thick packages of halite and white anhydrite, calcilutites, shales and marl.
Florianópolis Formation	Fine to coarse, red sandstones with clayey matrix, shale and micromicaceous red siltstones
Guarujá Formation	Bioclastic oolitic calcarenites that appear, varying laterally for cream-greyish / brownish-grey calcilutites and grey marl.
Itanhaém Formation	Pelitic package occurs between the clastics of the Itajaí-Açu Formation and the carbonates of the Guarujá Formation.
Santos Formation	Clusters and reddish lithic sandstones occur interspersed with grey shales and red clays.
Itajaí-Açú Formation	Pelitic package sotoposto and interdigitated with the clastics of the Jureia and Santos formations. It is composed of a thick section of fine clastics and the predominant lithology is dark grey shale.
Jureia Formation	Dark grey to greenish and reddish-brown shales, dark grey siltstones, fine and very fine sandstones and light cream calcilutites.
Iguape Formation	Bioclastic calcarenites and calcirruditesthat occur interspersed with greenish-grey clay, siltstone, marl and conglomerates.
Marambaia Formation	A thick section of shale and light grey marl intersecting with fine turbiditic sandstones.

Table 2. Geological units at Santos Basin and its main features. Source: Ciotta and Tassinari, 2020.

The choice of the most appropriate formations for CO_2 storage goes through two main criteria: initially, those that meet the suitable geological criteria are selected; secondarily, the depleted oil and gas fields, a situation considered most appropriate for application in the Santos Basin. When considering the use of depleted hydrocarbon fields, it is essential to note that the exploratory use of the

Santos Basin is recent, and only the Merluza Field currently fits into this scenario. It is possible to explore other areas thinking about a future situation, but for the scope of this work, the focus was on the Merluza Field. In this sense, the chosen units include the sandstones of the Juréia and Itajaí-Açu Formations corresponding to the Ilhabela Member. The subsequent subsection presents the criteria of choice based on the Merluza Field. It is evident that other possibilities exist, requiring a more detailed investigation of each particular case. However, for the scope of this work, the following topics seek to comment on the selection made.

3.3. Merluza Field study case

The Merluza platform (PMLZ-1) (figure 2) has been in operation since 1993 and produces the Merluza and Lagosta natural gas fields. It is located about 180 km off the coast of Praia Grande (SP), a fixed platform on a water sheet of about 131 m (PETROBRAS, 2019). The Merluza Field is equivalent to the first commercial gas discovery in risk contract drilling on the Brazilian continental shelf, carried out by Pecten Brazil Exploratory Company. Due to mechanical problems, the first well drilled in this field (1-SPS-11) was not adequately assessed. The second well (1-SPS-21), in turn, reached reservoirs at the base of the Juréia Formation, saturated with gas. In 1984, the drilling of well 1-SPS-20 in the bathymetric quota of 122 m allowed the evaluation of gas-saturated reservoirs in reservoirs of the Itajaí Formation, Ilhabela Member (SOMBRA et al., 1990).

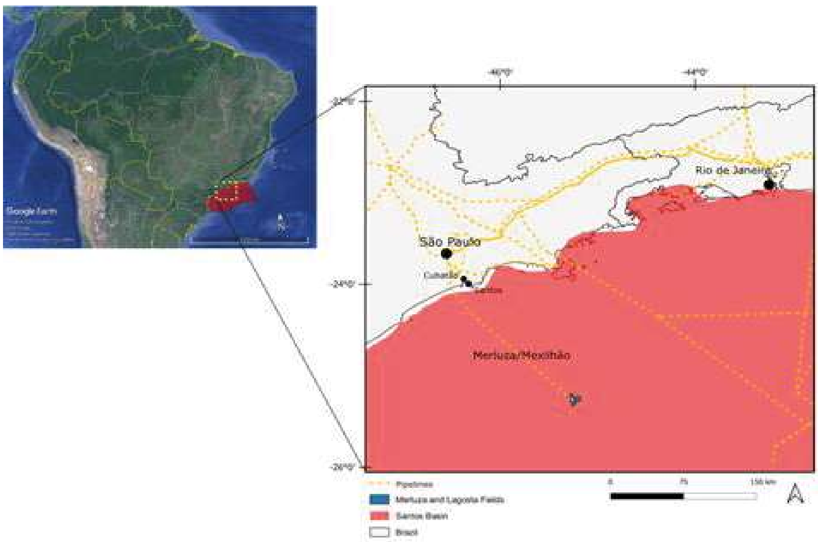

Figure 2. Merluza Field location. Source: Ciotta and Tassinari (2020).

The Merluza Field has two reservoirs of the Santonian age (Upper Cretaceous between 86.3 million and 83.6 million years ago). There are the sandstones of the Juréia Formation, whose deposition took place in the shallow platform. There is also the sandstones of the Itajaí-Açu-Member Ilhabela Formation, beds and channels in neritic slope (region of the oceans that corresponds to the relief of the continental platform and the water layer without tidal influence), presenting average porosity of 16% and permeability of 12 mD (SOMBRA et al., 1990).

The presence of usable infrastructures for CCS is another criterion favouring the choice of the Merluza Field as a location for the geological storage of CO_2. Engaging existing infrastructures is relatively cheaper than constructing new ones (HANNIS et al., 2017). In the Merluza Field, depleted hydrocarbon reservoirs are available, and the existing pipelines are favourable for transporting the captured CO_2 to the storage site to curb continental emissions.

Criteria	**Note**
Average porosity	Ilhabela Member - 21% a 4 700 m Ilhabela Member - 16% a 4 900 m Jureia Formation - 12% a 4 450 m
Porosity (qualitative comments)	In both reservoirs, the macroporosity is almost entirely intergranular, of primary origin. Volcanic feldspars and lithoclasts appear poorly dissolved. Higher levels of calcite in the Ilhabela Member occur close to the shales, indicating that the acidic fluids that originated in the shales were ineffective in dissolving the reservoir constituents.
Permeability	Ilhabela Member (1-SPS-20) - 10 a 100 mD Ilhabela Member (1-SPS-25) - 1 a 5 mD Jureia Formation (1-SPS-25) - 10 a 100 mD
Tectonic stability	The tectonically stable environment in general.
Reservoir characteristics	Lithic arcosios/arcosios constitute both reservoirs without significant variations in their detrital compositions—predominant lithoclasts: intermediate and acidic volcanic rocks, and in lesser basic volcanic quantities.
Clay minerals	Ilhabela Member - presence of chlorite fringes.
Degree of exploitation	High exploratory knowledge.
Infrastructure	Fixed platform; exclusive pipeline.

Table 2. Favourable criteria for the use of the Merluza Field for geological CO_2 storage.
Source: Ciotta and Tassinari, 2020.

The estimated CO_2 storage capacity of Merluza Field is 49,9 $MtCO_2$[1] (CIOTTA, 2020). The capacity estimation encourages the current study and planning of a viable CO_2 storage project. It is possible, for example, to consider the emissions of a given plant located in the Santos Basin coastline and examine if the chosen field can store the emissions emitted in the industrial processes.

4. CONCLUSIONS

The search for geological reservoirs is a relevant part of CO_2 capture and geological storage undertaking. The Santos Basin is strategically located due to its proximity to centres that emit greenhouse gases and the availability of oil-producing fields throughout its extension. The search for suitable regions for storage seems a logical path for the portfolio of CO_2 capture and geological storage in the Basin.

The use of the future depleted fields of the Santos Basin seems promising, both because it is an alternative to simple decommissioning in a world that is seeking solutions for its greenhouse gas emissions and because it takes advantage of the advanced geological knowledge and available infrastructure. The proximity of the Merluza Field to its decommissioning period suggests that it can be used as a CCS pilot project in the Santos Basin.

Finally, the search for geological reservoirs for CO_2 storage, even though incipient, is a process that makes sense within the dynamics in which the oil market and any enterprise that results in greenhouse gas emissions (Brazilian and worldwide) are inserted. As structured in this work, the analysis of local possibilities requires obtaining accurate data, but estimates and indications can be made.

It is worth noting that the study of potential results from an interconnection of factors: studying the feasibility of these developments requires the analysis of different parameters acting together. Therefore, an investigation that considers various factors involving economic and geological analysis is pertinent. With this type of information at hand, it is possible to zone areas of greater interest to be investigated with greater precision.

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1 New methodologies show more accurate data but they are still being published in peer-reviewed journals.

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REFERENCES

AMINU, M. D., NABAVI, S. A., ROCHELLE, C. A., MANOVIC, V. A. Review of developments in carbon dioxide storage. Applied Energy, v. 208, p. 1389-1419, 2017

ANP. Interpretação e Mapeamento de Sistemas Petrolíferos da Bacia de Santos: Tomo 1.180p., 2003.

ASMUS, H. E.; BAISCH, P. R. Geological evolution of the Brazilian continental margin. Episodes: Journal of International Geoscience, v. 1983, n. 4, p. 3-9, 1983.

BACHU, S. Sequestration of CO_2 in geological media: criteria and approach for site selection in response to climate change. Energy conversion and management, v. 41, n. 9, p. 953-970, 2000.

BACHU, S.; BONIJOLY, D.; BRADSHAW, J.; BURRUSS, R.; HOLLOWAY, S.; CHRISTENSEN, N. P.; MATHIASSEN, O. M. CO_2 storage capacity estimation: Methodology and gaps. International journal of greenhouse gas control, v. 1, n. 4, p. 430-443, 2007.

CHANG, H. K.; KOWSMANN, R. O.; FIGUEIREDO, A. M. F.; BENDER, A. Tectonics and stratigraphy of the East Brazil Rift system: an overview. Tectonophysics, v. 213, n. 1-2, p. 97-138, 1992.

CHANG, H. K. Sistemas petrolíferos e modelos de acumulação de hidrocarbonetos na Bacia de Santos. Revista Brasileira de Geociências, v. 38, n 2, p. 29-46, 2008.

CIOTTA, M. R. Estudo de possibilidades para armazenar CO_2 em reservatórios geológicos offshore na Bacia de Santos. 2019. Dissertação (Mestrado em) - Instituto de Energia e Ambiente, University of São Paulo, São Paulo, 2020. doi:10.11606/D.106.2020. tde16032020-221515. Acesso em: 2020-06-02.

CIOTTA, Mariana Ramos; TASSINARI, Colombo Celso Gaeta. Preliminary basin-scale assessment of CO_2 geological storage potential in Santos Basin, Southeastern Brazil: Merluza Field study case. Brazilian Journal of Development, v. 6, n. 9, p. 65961-65977, 2020.

EPE. 2019. Zoneamento Nacional de Recursos de Óleo e Gas. 607p.

FREITAS, A. F. D.; MOREIRA, D. B. R.; FILHO, E. P. C.; DIOS, F. B. R.; SILVA, T. C. S. D. Bacia de Santos: Estado da Arte, 90p., 2006.

GLADCZENKO, T. P.; HINZ, K.; ELDHOLM, O.; MEYER, H.; NEBEN, S., SKOGSEID, J. South Atlantic volcanic margins. Journal of the Geological Society, v. 154, n. 3, p. 465-470, 1997.

HANNIS, S.; LU, J.; CHADWICK., A. HOVORKA, S.; KIRK, K.; ROMANAK, K.; PEARCE, J. CO_2 storage in depleted or depleting oil and gas fields: What can we learn from existing projects?. Energy Procedia, v. 114, pp. 5680-5690, 2017.

IEA. Storing CO_2 underground. 19p., 2007.

IEA. 20 Years Of Carbon Capture and Storage: Accelerating Future Deployment, OECD Publications, Paris, 115p., 2016.

LLAMAS, B., ARRIBAS, M., HERNANDEZ, E., MAZADIEGO, L. F. Pre-Injection Phase: Site Selection and Characterisation. CO_2 Sequestration and Valorisation, Publ. by INTECH, p. 281-303, 2014.

MACEDO, J. M. Evolução tectônica da Bacia de Santos e áreas continentais adjacentes. Bol. Geoc. Petrobras, v. 3, p. 159-173, 1990.

PETROBRAS. Merluza. Comunicação Bacia de Santos. https://www.comunicabaciadesantos.com.br/empreendimento/merluza (accessed 25 May 2019). 2019.

ROCKETT, G. C. Associação de fontes emissoras e reservatórios potenciais para armazenamento geológico de CO_2 na Bacia de Campos, Brasil, 202p., 2010.

ROCKETT, G. C.; KETZER, J. M. M.; RAMÍREZ, A.; VAN DER BROEK, M. CO_2 Storage Capacity of Campos Basin's Oil Fields, Brazil. Energy Procedia, v. 37, p. 5124-5133, 2013.

SOMBRA, C. L., ARIENTI, L. M., PEREIRA, M. J., MACEDO, J. M. Parâmetros controladores da porosidade e da permeabilidade nos reservatórios clásticos profundos do Campo de Merluza, Bacia de Santos, Brasil. Boletim de Geociências da PETROBRAS, 4. 4: 451-466, 1990.

TOMIĆ, L., MARICIC, V. K., DANILOVIC, D., CRNOGORAC, M. Criteria for CO_2 storage in geological formations. Podzemni radovi, n. 32, p. 61-74, 2018.

UNFCCC. Adoption of the Paris Agreement. Report No. FCCC/CP/2015/L. 9/Rev. 1, http://unfccc. int/resource/docs/2015/cop21/eng/l09r01.pdf (UNFCCC, 2015)

WRI - WORLD RESOURCES INSTITUTE. Climate Analysis Indicator Tools. http://cait. wri.org/ (accessed 10 October 2019). 2019.