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The CARBMAP Project: Matching CO_2 Sources and Geological Sinks in Brazil using Geographic Information System

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Abstract

CO_2 capture and storage become an interesting strategy to mitigate climate change by reducing CO_2 emission from stationary sources and storing it in geological reservoirs. Taking into account that Brazilian territory contains many sedimentary basins suitable for CO_2 storage, the study of the Brazilian potential for carbon sequestration is relevant. This paper aims to present results of the Brazilian Carbon Geological Sequestration Map (CARBMAP Project). CARBMAP's goal is to identify appropriate sites for long term CO_2 storage in petroleum fields, saline aquifers and coal seams by an integrated geographic information system (GIS) and to generate products that will allow direct and detailed analysis regarding the CCS chain (capture, transport and storage) in Brazil, based on the development of a GIS for CO_2 source-sink matching. The Phase I of CARBMAP research began in 2006 – 2007 with the mapping of Brazilian stationary CO_2 sources, using a geographic database. The Phase II is underway, and is characterized by quantitative and qualitative improvement of the GIS resulting in more accurate products.

Keywords: CO_2 capture and geological storage; GIS; source-sink matching; Brazil; CARBMAP.

1. Introduction

The carbon capture and storage (CCS) is one of the most promising technologies to reduce greenhouse gases emissions and can contribute up to the 20% of global emissions by 2030 and 40% by the end of this century according to International Energy Agency. In a world level, emissions from burning fossil fuel are responsible for 70% of the CO_2 in the atmosphere, while other 30% of the emissions are from deforestation and land-use change. Even with a clean energy matrix – 75% of the Brazilian CO_2 emissions come from deforestation – Brazil is expected to increase its consumption of fossil fuels in the coming years, especially with the exploitation of "pre-salt" petroleum reserves.

Brazil recognizes the relevance of this technology in its National Plan on Climate Change as an alternative to reduce greenhouse gas emissions. It also recognizes that the growth of emissions in the country, related to the use of fossil fuels may require the use of technologies that can reduce emissions on a large scale, such as CCS. According to Cunha et al. [1], Brazil is engaged in climate change mitigation despite not having compulsory international greenhouse gases emissions reduction targets. There are governmental and private investment in studies in the area of CCS in Brazil, and many studies are being conducted in different research lines at the Brazilian Carbon Storage Research Center (CEPAC) since its inauguration in October 2007.

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2. The CARBMAP Project

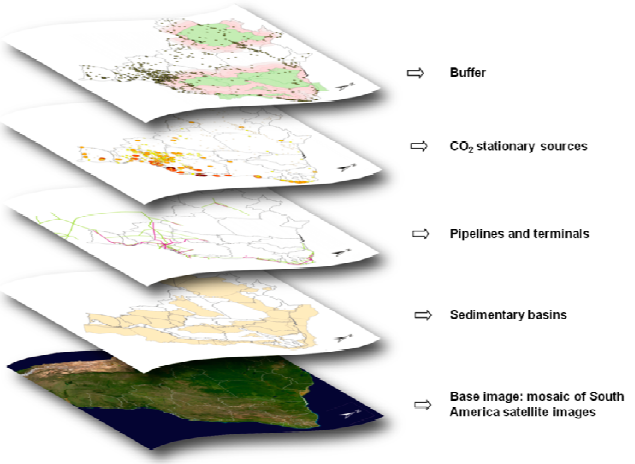

Figure 1. Representation of data overlaying for geographic analysis (CEPAC/PUCRS).

The Brazilian Carbon Geological Sequestration Map (CARBMAP Project) is developed at the Brazilian Carbon Storage Research Center and is supported by the Pontifical Catholic University of Rio Grande do Sul since 2006. CARBMAP's objective is to develop and manage a Geographic Information System (GIS) on carbon capture and storage (CCS) and create products to support analysis of the Brazilian potential for CO_2 sequestration. Using the software ArcGIS 9.3.1 all the georeferenced data regarding the CCS chain – CO_2 sources, transport infrastructure and geological sinks – were matched and assessed through geoprocessing techniques (Figure 1).

3. CARBMAP – Phase I

3.1. Mapping stationary CO_2 sources and sinks in Brazil

In phase I of the CARBMAP Project (2006 - 2007) Brazilian stationary CO_2 sources were mapped, as well as all the sedimentary basins onshore and offshore Brazilian territory, by means of a Geographic Information System (ArcGIS). Information from the International Energy Agency's CO_2 emissions database [2] and the Ministry of Science and Technology [3] were compiled and corrected, by checking geographic coordinates and adding missing data [4]. A total amount of 204 $MtCO_2$/year was mapped from 361 stationary sources. The CO_2 stationary sources data collection allowed the allocation and identification of each source's sector in Brazil. It was identified plants on many sectors, such as cement production, power production, refineries, ethylene production, iron and steel plants, biomass, ethanol production and one ammonia production plant. Note that the inventory of CO_2 sources contains only onshore sources, but there is a high potential for CCS from capturing carbon dioxide from offshore sources (petroleum industry CO_2 sources).

Regarding sinks, Brazil has extensive areas with potential geological reservoirs, consisting of 32 onshore and offshore sedimentary basins formed in different ages (Proterozoic to Cenozoic). Currently there are in Brazil 22 basins with active hydrocarbons exploration and production, with a total proven reserves of more than 12.8 billion barrels of oil (93% located offshore) and 364 billion cubic meters of natural gas [5]. Campos Basin is the most prolific basin, with more than 80% of Brazilian petroleum reserves [6]. Sedimentary basins that contains coal are specifically located in south part of Brazil, mostly in Paraná, Santa Catarina and Rio Grande do Sul states.

3.2. CO_2 storage capacity estimation

A preliminary theoretical CO_2 storage capacity's estimation in hydrocarbon fields, aquifers and coalbeds was performed for each basin in Brazil. The equivalent CO_2 mass that can be stored was estimated based on the oil and gas reserves and cumulative production [7]. The estimatives showed that Brazil has a high potential for carbon capture and storage. The results show that Brazilian sedimentary basins could store more than 2035 Gt of CO_2 in aquifers, petroleum fields and coal seams [8]. CO_2 storage capacity for oil and gas fields is of about 4 Gt (taking into account

petroleum reserves and cumulative production), being 1.7 Gt specifically in Campos Basin (only taking into account oil/gas reserves). Coal seams CO_2 storage capacity was estimated in 170 Mt and a preliminary theoretical storage capacity in aquifers is ca. 2030 $GtCO_2$. Figure 2 shows the theoretical capacities for CO_2 storage in petroleum fields of each basin, based on petroleum reserves [9].

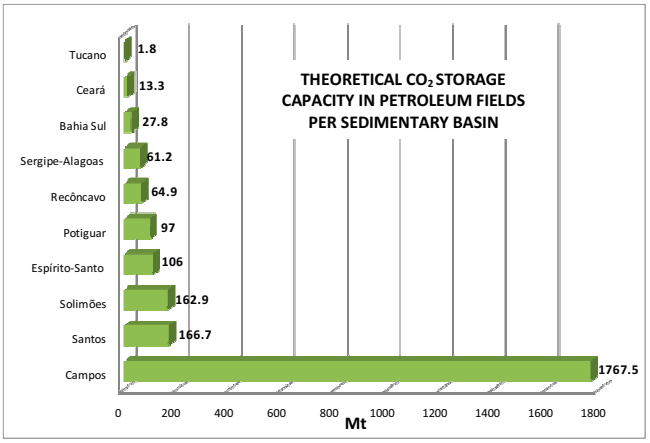

Figure 2. Theoretical CO_2 storage capacity in Brazilian oil and gas fields [9].

3.3. Preliminary CO_2 source-sink matching in Brazil

A preliminary source-sink matching was performed by overlaying the map of Brazilian sedimentary basins and the map of CO_2 emission. The resultant map shows that most of the CO_2 sources are close to sedimentary basins in Brazilian territory (Figure 3). Some preliminary analysis allowed us to conclude that the concentration of CO_2 sources in Brazil are located in the southeastern and southern Brazil, with major concentration in São Paulo state [8].

A 300 km radius buffer was generated around each sedimentary basin limit by geoprocessing techniques and the amount of CO_2 available per sink within this distance was estimated. Results show that the majority of CO_2 sources are matched to the non-prolific Paraná basin (135 $MtCO_2$; [8-10]) and to the prolific Santos Basin (80 $MtCO_2$; [8]).

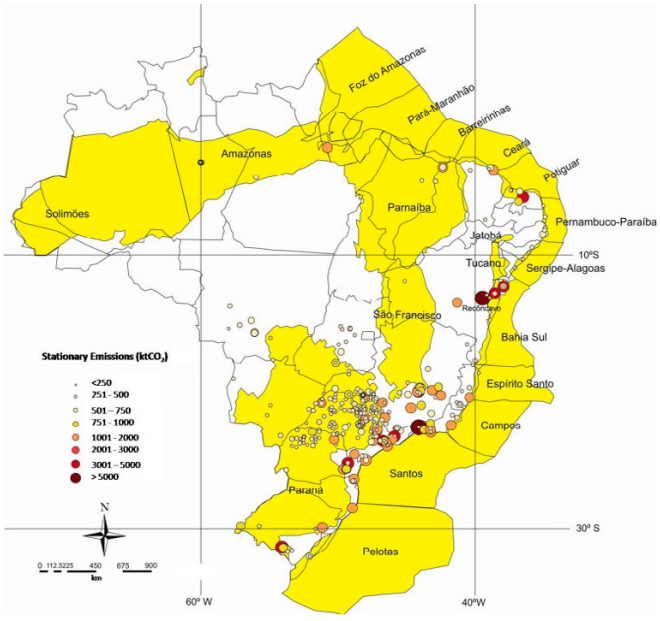

Figure 3. Brazilian CO_2 sources and sedimentary basins [8]

There is a mismatching between sources and sinks in Northern Brazil, with few matched emissions in large basins such as Amazonas and Solimões (2.5 Mt and 3 $MtCO_2$ per year, respectively [8]). Table 1 shows the six sedimentary basins with large matched CO_2 emissions in Brazil.

Table 1: Matched CO_2 emissions in 5 "good matched" basins in Brazil [8-9]

Sedimentary Basin	Matched CO_2 emissions (Mt/year)
Paraná	135*
Santos	80
São Francisco	37
Campos	30.6
Espírito Santo	8

* Refined source-sink matching, taking into account a 300 km radius buffer from the 800-2,000 meters depth isopach [10]

The source-sink matching analysis was done in detail for a particular sedimentary basin in southern Brazil (Paraná Basin), by means of considering the depth of Rio Bonito Formation – the main geological formation which contains the best reservoirs in Paraná basin, according to Zalán et al. [11] – and its thickness. The Rio Bonito Formation isopachs were georeferenced and added to the GIS for the matching analysis. Then, a 300 km radius buffer was generated around the 800-2,000 meters isopach (optimal depth for CO_2 storage) of Paraná Basin, resulting in a more refined matching [10] (Figure 4a).

In Rio Grande do Sul state (south of Brazil, and which covers the southern part of Paraná Basin) an assessment on potential areas for CO_2 geological storage was performed, taking into account Rio Bonito Formation optimal depth for CO_2 storage. High potential areas correspond to areas in which Rio Bonito Formation is deeper than 800m (Figure 4b). A wide area from east to west in the center of Rio Grande do Sul has a high potential for CO_2 geological storage [12-13], whereas the north and south portion of the territory are not potential for this activity. CO_2 storage potential in Paraná basin is related to saline aquifers and coal seams.

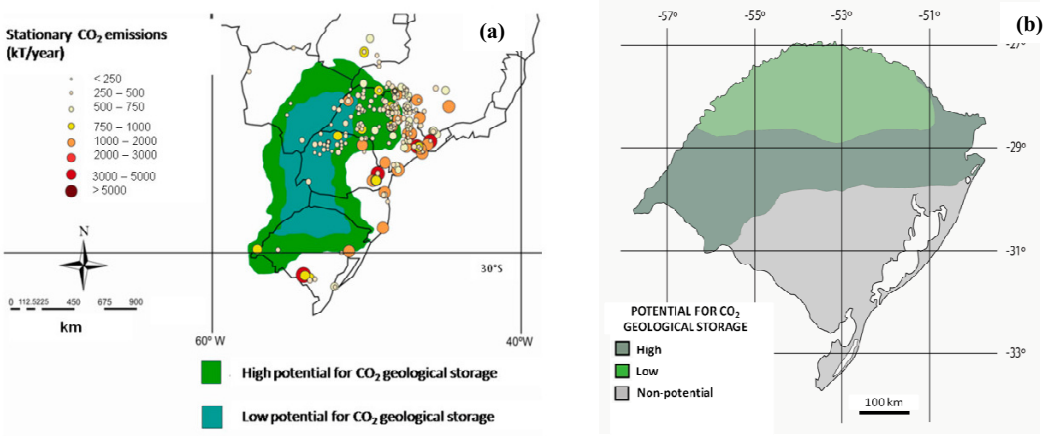

Figure 4. (a) CO_2 storage potential in Paraná Basin (800-2,000m depth) [10]; (b) CO_2 storage potential areas in Rio Grande do Sul state (only taking into account optimal depth: > 800m) [12-13].

In Phase I, the CARBMAP Project identified opportunities for CCS in Brazil in Paraná Basin (saline aquifers and deep coal), Campos Basin (petroleum fields and saline aquifers), Santos Basin (petroleum fields and saline aquifers) and Recôncavo Basin (petroleum fields and saline aquifers). There is potential for Enhanced Oil Recovery (EOR) in the prolific Campos and Santos offshore basins – due to the CO_2 in natural gas – and Recôncavo onshore basin – due to the EOR experience and infrastructure installed [8].

4. CARBMAP – Phase II

4.1. GIS database update

In the Phase II (2008-2010), the CARBMAP's database had a quantitative update which has been allowing a significant expansion of analysis on Brazil's potential for CO_2 sequestration. For instance, the sedimentary basins' layer already mapped in Phase I, were retraced with more accurate limits according to Milani et al. [14] and the stationary sources data were increased up to 1400 units in which 38% of the plants are responsible for emissions from 100 to 6300 kt/yr. After the update, the southeastern portion of the country still concentrates the higher density of CO_2 emissions (Figure 5).

Also, there was the update of transport infrastructure data such as: (i) pipelines constructed and in operation (oil/ore/gas); (ii) pipelines under construction or projected and (iii) pipelines under study.

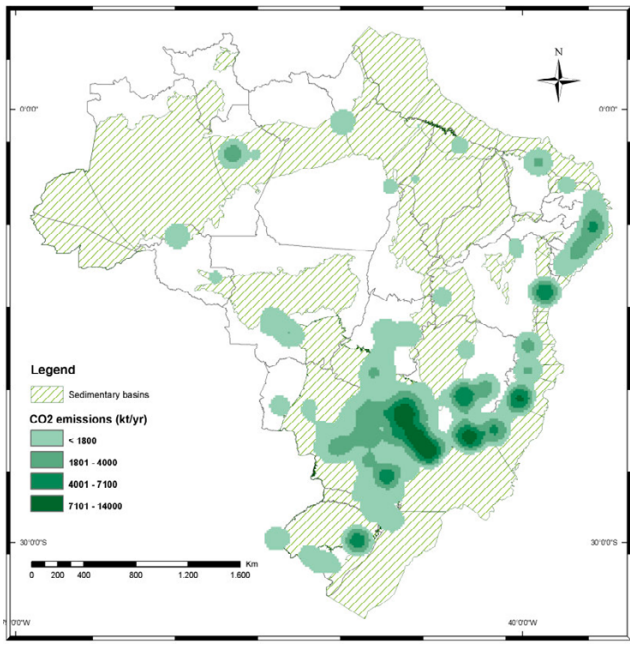

Figure 5. Brazilian CO_2 emissions density map (CEPAC/PUCRS).

An increase of more than 4000 km of pipelines, comparing to Phase I [5, 15-18], including the only CO_2 Brazilian pipeline, located in Bahia, which transports CO_2 from an ammonia plant and a petrochemical plant to the Buracica field at Recôncavo basin.

4.2. Database improvement

The stationary sources database allowed the allocation and identification of each Brazilian source sector. It was identified plants on cement production, power production, refineries, ethylene production, iron and steel plants, biomass, ethanol production and ammonia production. The CO_2 emission was estimated by multiplying the physical power of each source per the plant work hours and per the emission factor [19]. The next step was obtaining data from IEA GHG [2] and ANEEL [17] and the classification of source sector and type of fuel used which were useful for the definition of the suggested capture technology for each source. Focusing a safety analysis, drilled wells were inputted in the GIS.

Capacity calculations were improved by refining data on oil, gas and coal production from ANP [5]. For source-sink matching purposes it's important to consider existing hydrocarbons production infrastructure since it may have a positive impact on the whole project cost and licensing. Owing to the insufficient data on Brazilian saline aquifers, data on hydrogeologic provinces and aquifer systems were used instead.

4.3. CO_2 source-sink matching

The coalbeds were recently identified as potential CO_2 geological reservoirs. The Brazilian largest coalbeds are located in Paraná's basin. The CO_2 sources and coalbeds matching was assessed [20] based in the following criteria: (i) coalbed occurring at a depth upper than 300 m; (ii) stationary sources occurring at distance lesser than 300 km from the reservoir limit; (iii) effective capacity of CO_2 retaining between 50-70%; (iv) matched capacity in which was considered the

amount of stored CO_2 considering the whole useful life of the coalbed as a reservoir. It was found that the amount of CO_2 matched with coalbeds is over 65000 kt/yr, 21% of the Brazilian stationary sources emissions (Figure 6).

In 2009, the CEPAC research team, composed by geologists, geographers and chemists, gathered to assess CARBMAP's database and rank sedimentary basins according to its CCS prospectivity potential considering geological and geographic criteria. Eight criteria, equally weighted, were considered on the basins' evaluation.

The ranking was established by adding the grades to obtain the prospectivity potential. The results show that 19% of all sedimentary basins have high potential for CCS, otherwise, the half of them have low potential (Figure 7). The insufficient geological information is probably the reason why the majority of the basins were classified as low potential. The complete methodology and the assessment results will be published in the Brazilian Atlas on CO_2 Capture, Transport and Geological Storage, under elaboration [21].

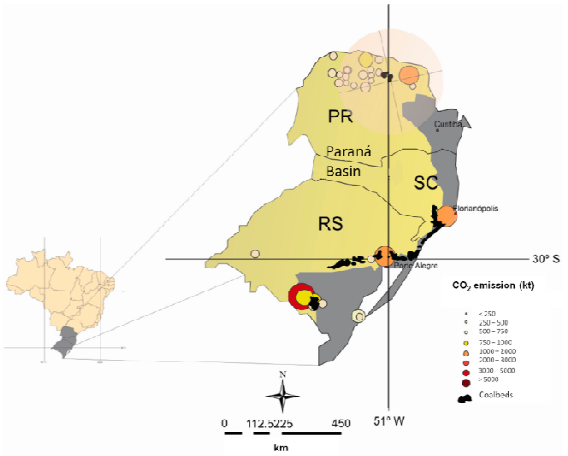

Figure 6. Paraná's basin coalbeds CCS potential [20].

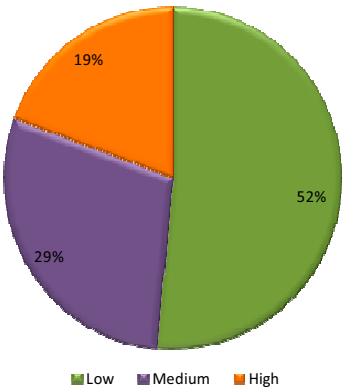

Figure 7. Percentage of basins per prospectivity potential.

Focusing on Brazil's potential to renewable carbon capture and storage (RCCS) – 46% of the produced energy come from renewable sources [22] – CARBMAP started to develop its map in 2010. The preliminary matching of (i) sugar; (ii) ethanol; and (iii) sugar and ethanol plants – whose CO_2 emissions are almost pure and significantly diminish capture costs –, transport infrastructure and geological reservoirs showed a significant potential for RCCS in Brazil. The first preliminary results show that all these sources – a total of 476 plants – emit 89,6 Mt of CO_2 and are located within a maximum distance of 300km from the sedimentary basins' limit.

5. Final remarks

The CARBMAP Project results show significant potential for carbon capture and storage in Brazilian sedimentary basins' petroleum fields, coalbeds and saline aquifers. The project also pointed that the actual insufficient of information in some research areas was crucial in the CCS prospectivity assessment. Owing to its low economical interest, non-prolific basins are poorly studied difficulting more accurate capacity. It was possible to identify opportunities for CO_2 storage in a national level in Paraná, Campos, Santos and Recôncavo basins. Taking into account the CARBMAP data's improvement in phase II, more accurate source-sink matching is being assessed at CEPAC as well as more realistic storage capacity estimations.

The CARBMAP's next steps will be the continuous database update aiming more accurate assessment and also include economic parameters in the basins' prospectivity.

6. Acknowledgements

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