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Carbon Capture and Storage (CCS) in the Context of Petrobras, the Main Brazilian Oil Company

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Abstract: Sustainability and climate change are central themes for the survival of living beings on Earth. In this context, carbon capture and storage (CCS) is being considered one of the most effective emission mitigating alternatives for global warming gases. Environmental and social risks are still questioned in these studies, because they are very recent with few historical data, regarding the storage issue. In such context, the present article objective to discuss how this process works, advances, possible impacts and working in exploration context and production activities led by Petrobras, the largest company of the country and of the Latin America. The Petrobras is one of the largest sources of stationary CO_2 emissions in Brazil. This article is composed of exploratory subject research with institutional and international documents about the latest developing technology in the world. Based on the present study results, the technology (CCS) combined with renewable energies effective scale-up and energy efficiency is fundamental to achieve the sustainability goals and create an effective mitigation for carbon dioxide emissions. In addition, the analyzed primary data confirm that article mentioned combination together with a shift in lifestyles behavior is an excellent alternative for the mitigation of the climate change.

Key words: mitigation strategies, carbon capture and storage (CCS), petrobras

1. Introduction

Planet Earth has gone through critical changes in the last decades and these have been subject to discussions, mobilizations, and actions on every instance, whether they are governmental, entrepreneurial, or educational along with families and communities. Such changes come from the exponential multiplication of inhabitants in these last few decades. Humanity's pursuit quality of life and meeting their needs figures well beyond the planet's reposition capability. The Global Footprint Network (2016) [1], research organization that measures man's ecological footprint in our Planet, affirms that until 2015 humanity would have consumed 1.6 planets Earth. This deadweight loss, which our small world is not capable of reverting, has accumulating since the 80s, the main factor being the population boom to 11 billion inhabitants, baseline that tends to approach by the end of this century.

One of the aspects permeating the ecological footprint along with the growing worldwide population index is the carbon footprint, which is, the CO_2 quantity emitted by each human being. More than that, it also is the amount of CO_2 emitted necessary to keep a lifestyle for which the demand for fossil fuels increasingly grows and which base is on the extraction of ores and water through extensive agriculture, among other types. Beyond the CO_2 atmospheric concentration that has been increasing yearly, there is no systemic vision of future necessities on the waste of natural resources. CO_2 is among the substances responsible for global warming and is the main issue of many global conferences on climatic changes, the

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United Nations Conference of the Parties with participation of various countries.

In the Conference of the Parties — COP 21, set in Paris, the Paris Agreement was created and signed, at that time, by 195 nations associated with the United Nations. Such global climate agreement, after several ratifications from almost all of the signatory countries, inured in November 2016; finally, in last instance, the COP means the diplomatic effort of more than 190 nations to combat emissions of greenhouse gases and limit the rise of average global temperature to much less than 2°C until the end of the current 21st century.

However, for the contention of global warming, it is necessary to shift the inhabitants' lifestyle, look for alternative energy sources, diminish dependency on fossil fuels, and eliminate deforestation, among many other activities of the current generation. More than that, it is essential that countries comply with the agreements formalized in COPs and project effective legislations and regulations with penalties and fines in their countries.

As this revolutionary adjustment is still under discussion and work on governmental, entrepreneurial, academic, and civil orders; one of the forms to mitigate CO_2 emission is utilizing modern tools and processes directly from the emission sources. These CO_2 emission sources can be stationary or mobile, that is, can be static — such as factories, refineries, powerplants based on coal and gas, among others — or can move — for example trucks, boats, cars, planes, etc.

For the stationary emission sources, it is easier to map and use the mitigation technique that is the Carbon Capture and Storage (CCS). This modern technique of diminishing direct CO_2 emission to the atmosphere started in 1996 with the first large-scale implementation in an emission source [2].

Therefore, this article pursues demonstrating the functioning of this process, its progresses, and possible impacts. Finally, this article also demonstrates how it is being used in Brazil in one of the biggest stationary emission sources of Petrobras, the largest energy and oil venture in the country.

2. Carbon Capture and Storage (CCS)

The CO_2 Capture and Storage or, in last instance, Carbon Capture and Storage (CCS) — has the potential to be one of the solutions in order to diminish the emissions that lead the increase of global warming. According to IEA (2016) [2], CCS is the only technology capable to promote significant reductions in fossil fuels use for energy generation in the industry. When combined with other sources like bioenergy, CCS can also remove CO_2 from the atmosphere and generate "negative emissions", which is an option to delimitate future temperature increases under international agreements.

The document Special Report on Carbon Dioxide Capture and Storage [3] defines the capture and storage of carbon dioxide (CO_2) is a process that splits CO_2 in industrial processes and energy sourcing, which is mostly stationary fonts; from this separation, CO_2 is carried to long-term storage and isolation of the atmosphere. This report also considers CSS as an alternative action to mitigate greenhouse gases and to stabilize in the atmospheric concentrations.

Other mitigation options has been provided by the report [3] including energy efficiency improvements, shift to less carbon-intensive fuels, nuclear energy, renewable energy sources, increase biologic sinks and greenhouse gases reduction (non-CO_2). According to IPCC (2005) [3], CCS has the potential to reduce global costs of mitigation and increase flexibility in reducing greenhouse gases. However, the document states that the CCS widespread application will depend on technical, cost, global potency, diffusion, and developing countries energy transference maturity and also their applying capacity of this technology, the regulatory aspects, environmental matters and public perception.

The CCS impacts are under studies across the last two decades, and as observed, there are many projects being implemented and others under work. According to IEA (2016) [2] until this report date, there was relatively low investments in large-scale CCS projects due in part to the specific policies absence. The exception to this was the investment in projects that can guarantee an income flow from the sales of CO_2 in established North American markets.

CCS has to be applied under a large-scale aspect in order to achieve financial and technological success. According to IPCC (2005) [3], the large focal sources of CO_2 include:

- Large utilities for fossil fuel or biomass production;
- Main industries that emit CO_2;
- Natural gas production;
- Synthetic fuels factories;
- Factories of hydrogen from fossil fuels.

According to IPCC (2005) [3], the CO2 technical storage methods far from atmosphere, are these:

- Geological storage (into geological formations such as oil and gas fields, non-bordering coal roads and deep salt formations);
- Ocean storage (direct release into the water column of the ocean or deep sea bottom);
- Inorganic carbonates.

The following Figure shows the CO_2 storage forms according to the IPCC (2005) [3].

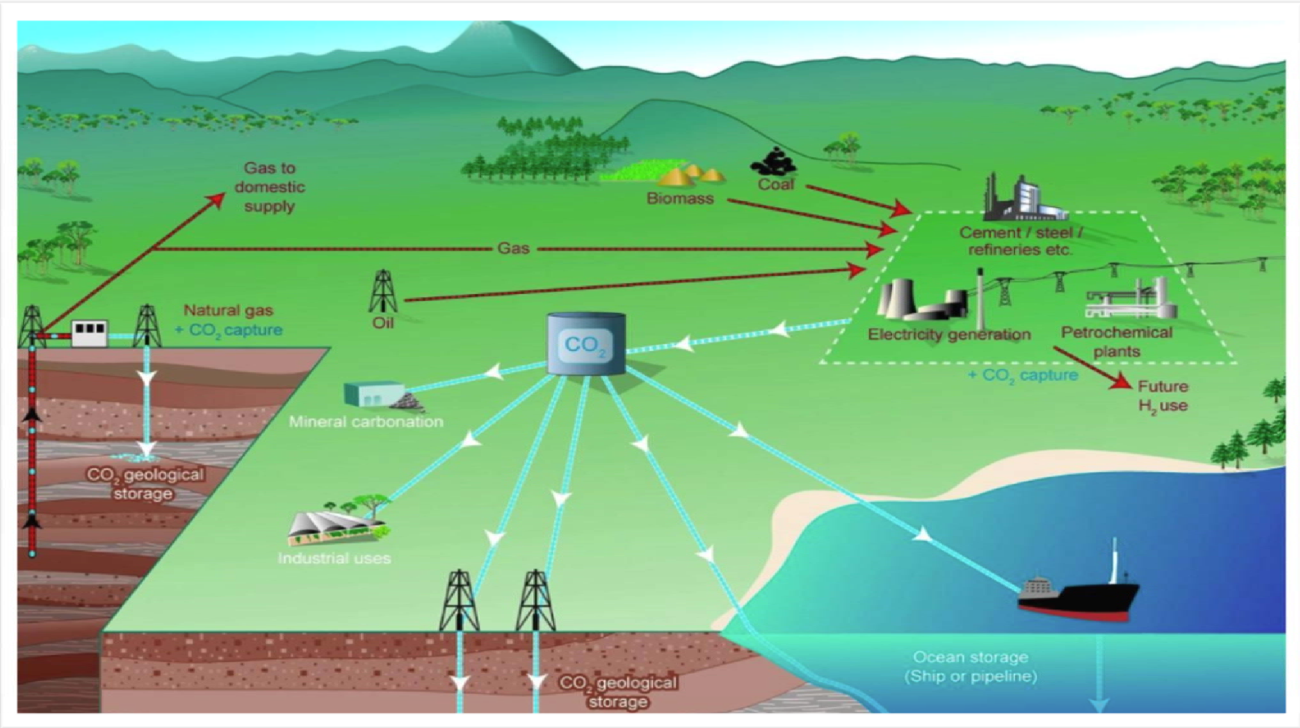

Fig. 1 Diagram of possible CCS systems [3].

According to the document that explains the CCS from IPCC (2005), for an estimated calculation of CSS's level utilization in the planet large stationary emission sources (> 0.1 $MtCO_2$ yr-1) were used involving the fossil fuels and biomass use. These fonts are present in three main areas:

- Fuel combustion activities;
- Industrial processes;
- Natural gas processing.

The largest CO_2 are by far result from carbon oxidation when fossil fuels are burnt [3] These emissions are associated with fossil fuels ignition in energy powerplants, oil refinery, and large industrial plants.

According to IPCC (2005) [3], emissions liquid reduction to atmosphere through CCS depends on the captured CO_2 fraction, the CO_2 production, resulted from the electric centrals or industrial processes efficiency loss due to the necessary additional energy for the capture, transport, and storage. In other words, it is necessary to calculate energy expended and how much CO_2 will be spent in this CCS process. However, the calculation is positive when well planned, as the following Fig. 2.

In order to capture CO_2 there are different types of processes, according to the IPCC (2005) [3], which are: post-combustion, pre-combustion and oxy-combustion. The CO_2 concentration in the gas stream, the gas current pressure and the fuel type (solid or gas) are important factors in the capture system selection. Regarding transport types and storage of CO_2, there are some types of CO_2 storage, but it is a last two decades techniques, it has not been possible to measure their long term direct impact.

According to IPCC (2005) [3], CO_2 storage in deep geological formations, onshore or offshore, uses most of the times the same technologies that were developed by petroleum and gas industries. These have shown as economically feasible under specific conditions for petroleum and gas fields and salt formations, but not yet for storing non-bordering coals reserves. If the CO_2 is injected in adequate saline formations or in petroleum or gas reserves [3] in depths below 800 meters, various mechanisms of physical and geochemical traps will impede CO_2 migration to the surface.

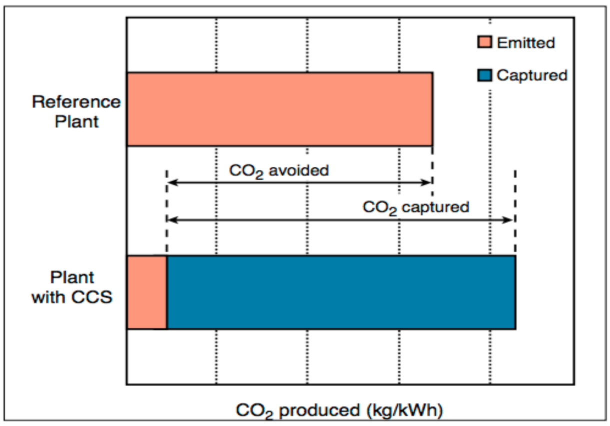

Fig. 2 CO_2 emissions difference [3].

Storing coal reserves can occur in smaller depths and depend on the coal's CO_2 absorption, but technical viability depends mostly on the permeability of the coal reserve. The CO_2 storing combination with the Enhanced Oil Recovery (EOR 11) or, potentially, the Enhanced Coal Bed Methane (ECBM) could lead to additional revenues from the recovery of petroleum or gas. The well drilling technologies, injection, computational simulations on the storage reserves performance, and the monitoring methods of the existing application are being developed to be applied in projects of geological housing conception and operation. As stated by IPCC (2005) [3], three tankage projects in industrial scale are operating: project Sleipner in a Norway saline offshore formation, Weor EOR in Canada, and project In Salah in a gas camp in Argelia.

Still according to IPCC Report (2005) [3], storing in the ocean could be done in two manners: injecting and dissolving CO_2 in the water column (typically below 1,000 meters) through tabulation or ships in movement, or depositing CO_2 through pipelines or an offshore platform. At depths below 3,000 m, where CO_2 is denser than water, it is expected to form a "lake" that would delay CO_2 dissolution in surrounding environment. The oceanic storage and its ecological impacts are still under research phase. Dissolved and sparse CO_2 would become part of the global carbon cycle and would eventually stabilize with atmospheric CO_2. In laboratory experiments, oceanic experiments were studied small-scale along with model simulations, technologies, chemical and physical phenomenon, which include, notably, acidity (smaller pH) increase and its effect in marine ecosystems.

As in every feasibility analysis, of resources and potential, CCS also requires geographic analysis. Thus, IPCC (2005) [3] explicates that large CO_2 emission fonts concentrate proximate to large industrial and urban areas. Many of these sources are within 300 km from areas that potentially contain adequate formations to geological housing. Preliminary research also suggests that globally only a small proportion of large punctual fonts is close to places with oceanic storage potential. Literature currently available [3] on the correspondences between large punctual CO_2 fonts and adequate geological formations is limited. Detailed regional evaluations might be necessary to improve information.

It is hence necessary a study on economic and geographic feasibility. This way, according to IPCC (2005) [3], scenarios studies indicate the number of large emission sources is expected to increase in the future and that by 2050, due to expected technical limitation, around 20 to 40% of global fossil CO_2 emissions can be technically adequate for capture — including from 30 to 60% of CO_2 energy generation emission, as well as 30 to 40% coming from industry. Emissions coming from large biomass conversion plants can also be technically adequate to the capture. The proximity of future emission sources to potential storing places have not yet been studied, which represents an excellent opportunity for economic feasibility analysis.

According to IEA's study from 2013 [4], there is a projection of capture and stocking growth for 2030 and for 2050, as represented in Fig. 3, counting with larger growth proportions in China and OECD Americas' area, as well as the rest of the main issuing countries.

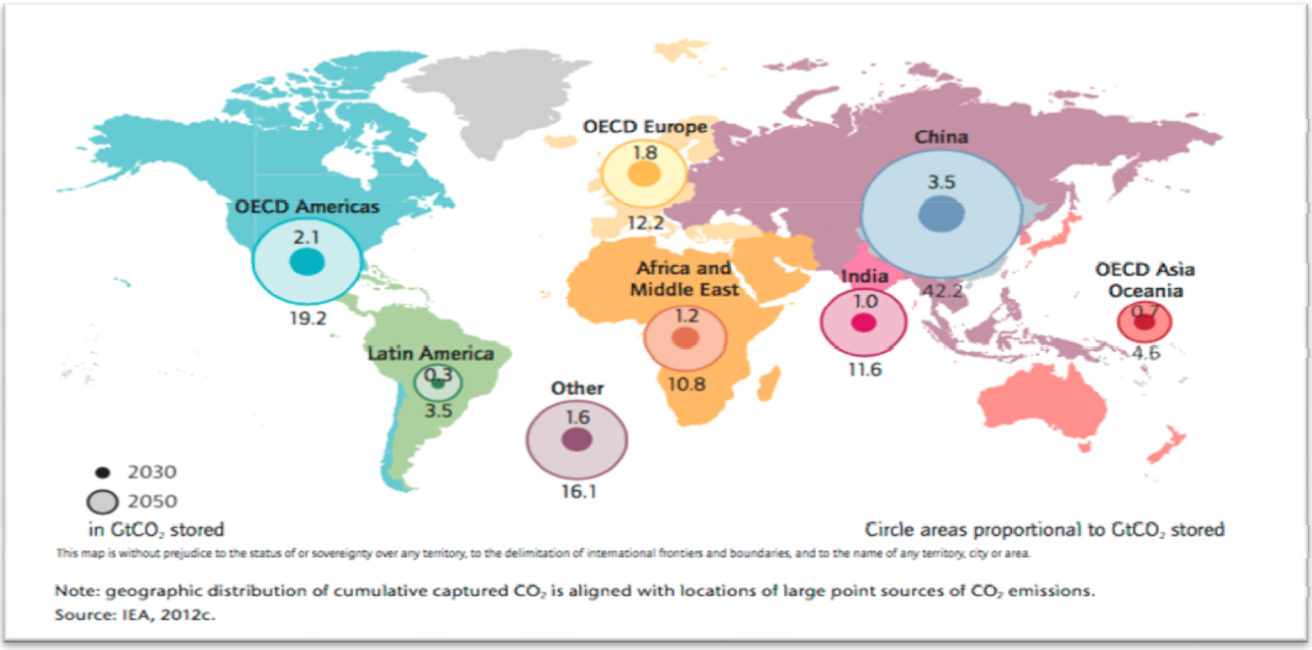

Fig. 3 Accumulated CO_2 from 2015-2030 to 2050 for each region of the planet [4].

It can be observed that growth expectancies are relatively big for the next years, though for it is necessary analyzing the impacts and financial evaluation of the current process, as well as improvements to be worked on.

3. Methodology

Ideally, the economic forces will not exclusively overweight the individual in command (a stakeholder, in particular) in the decision-making process related to environmental issues or, particularly, to the mitigation of global climate change. After all, the representativeness of a high-level manager of any business had in its trajectory an educational process that recognizes the "*business as usual*" will not be able to contain the devastating effects of climate changes and that each and every person has their own function concerning actions of prevention and mitigation. With this, in a long-term scenario, it is hope that the scenario tends to have a sensitive reduction in the mismatch of ventures' decision processes and environmental protection. This mismatch can be signalized in decisions that consider solely profit without considering tools of cleaner production — and that pass through and/or are tangent to CCS, for example — and the yearnings of the population, including of the company's collaborators, in relation to environmental matters.

In this context, therefore, the current study methodology is based in critical synergic analysis from select manuscripts published in scientific journals of renowned impact for the macro-area in which it figures, and that, in many ways, correlate themes of energy, climate changes, and CO_2 capture and storage. Hence, this present work is composed by exploratory research of the subject with institutional and international documents on the recent technology that is under development in the world.

4. Results and Discussions

In the Brazil's case, and in particular with regard to the performance of Petrobras, in the context of the development of the present work, it was possible to deduce that there are already currently (March 2018) two oil fields in which the combination of CO_2 storage with the Enhanced Oil Recovery (EOR). These are the plants of Araçá Leste, in the State of Bahia, in the Northeast Region of Brazil, and the Campo and Pojuca River, also located in Bahia.

First of all, it is fundamental to know one of the largest companies in Latin America and one of the main companies in Brazil. According to Petrobras (2017) [5], the company operates in the oil and gas sector, in activities of exploration and production, refining, marketing, transportation, petrochemicals, derivatives distribution, natural gas and gas chemistry, as well as electric power generation and production and marketing of biofuels. The company is a leading oil company in Brazil, with activities in Argentina, Bolivia, Colombia, the United States, Mexico, Nigeria, Paraguay and Uruguay. This large corporation is a mixed-holding company and the major shareholder is the Federal Union, which maintains control. The company develops products to meet the varied needs of final consumers and customers, such as road, agricultural, industrial, air, waterway, rail and thermoelectric markets. It also has a stake in companies responsible for the production of basic petrochemical products (such as ethylene, propene and benzene) and also raw materials for second-generation industries to manufacture other products (such as plastics and rubbers) used by leading industries in the production of articles for public consumption (such as packaging and tires).

According to the company's report of 2017 [5], the company places within its main products: diesel, automotive gasoline, natural gas, liquefied petroleum gas (LPG) and naphtha. Petrobras also owns 297 brands, working on 120 platforms, 7,888 production wells, 13 refineries, and 1 shale industrialization unit. They own 4 biodiesel production units in operation with 0.5 million cubic meters of biodiesel handled in 2017. They also handled 572 million cubic meters of petroleum and its by-products through its 55 vessels, 47 terminals and 7,719 km of oil pipelines. The company also has 20 thermoelectric plants that generated 3,800 average MW of energy in 2017.

In the case of Campo de Araçás Leste, it has a research and development utility area of 8.25 km² and is located in the portion that emerges from the Recôncavo Basin, just over 100 km from the city of Salvador, capital of the Bahia State. The Campo de Rio Pojuca is located in the municipalities of Pojuca and Mata de São João, in the State of Bahia. In a regional geological context, it is located in the Central Compartment of the Recôncavo Baiano Basin. It is emphasized that the Campo de Rio Pojuca is a concession, composed only of the Field of production. There is no oil or gas processing in this concession, nor natural gas compression or effluent treatment.

The International Energy Agency — IEA (2013) [4] estimates that for Latin America as a whole there is potential for carbon storage via CCS by 2050 of about 3.5 Gt CO_2 — of this carbon dioxide storage potential, it can be inferred from interpretations made with Petrobras that at least 50% would be in oil reserves located in Brazil. It can be observed that the growth expectation is relatively large for the coming years, but it is necessary to both analyze the impacts and financial evaluation of the current process, as well as the improvements to be worked on.

In the context of the present study development and regarding the role of Brazil and Petrobras in the context of CO_2 storage via CCS, it is observed that the actual realization of this potential depends and needs further studies and clarification for the general population, after all, lack of knowledge, doubts and concerns are many — as for example with the impacts of this technological procedure on abyssal marine life and even on possible deleterious influences (anticipatory for example) on the movement of tectonic plates inherent to the Brazilian Continental Shelf. Even with regard to the legal issue, there are some regulations for underground operations that may be relevant or, in some cases, directly applicable to geological storage. Brazil, as well as the vast majority of countries, has not yet developed, specifically, legal or regulatory frameworks and specific policies for long term CO_2 storage. The fact is that, even globally, there are currently gaps in available knowledge on some technological aspects for CSS full implementation. It was therefore envisaged that increasing knowledge and experience would reduce uncertainties and thereby facilitate decision-making regarding the CSS implementation for climate change mitigation.

In general, even in developed and CCS-eligible countries, CCS activities are recent and a new issue. Over the past two decades, recognition of CCS's role has developed in parallel with a global understanding of climate threats and mitigation options. For now, with no bias of scientific and/or technological conservatism, CCS represents a very promising technology. As supported by a number of studies led by the academy and the private sector, the CO_2 removal and storage from fossil fuels from the power station is feasible, but for some long-term CO_2 storage options, costs, environmental effects and these options effectiveness remain unknown. More recently, however, the IPCC's fifth assessment report (AR5) has identified CCS as critical and necessary to achieve more ambitious climate targets.

In Brazil, the fact is that, apart from the planning initiatives headed by Petrobras, the CCS has also been little studied. In general, Brazil is not against the use of CCS; however, the federal government understands that these technologies are not eligible as Clean Development Mechanism (CDM) projects for several reasons. The Brazilian government believes that CDM incentives should be widely used to promote cleaner and more renewable technologies, which clearly point to the current production decarbonization and consumption patterns and not to promote the use of oil, gas and coal.

CCS projects in developing countries could take place in another context, with specific financial mechanisms, funding and partnerships within the UNFCCC, but not as a compensation mechanism, generating carbon credits to be used by countries, as the CDM. The inclusion of CCS projects within the Clean Development Mechanism (CDM) may reduce the emphasis on seeking more appropriate financial mechanisms under the UNFCCC or government policies. Thus, CCS could be one of the bridge technologies until countries can have full confidence in renewable energies, but at the same time the CCS under the CDM would lead to perverse incentives for increasing fossil energy production in developing countries, which would strengthen the technological gap between the developed and the developing world.

According to Camara, Andrade and Rocha (2011) [6], if there is an incentive to use CCS technology in Brazil, whether through public financing or emission taxes, exploratory studies point to CO_2 mitigation potential, only for Pre-Salt and Recôncavo Basin oil provinces, estimated as a function of annual emissions capacity, a total of 26.4 Mt CO_2/year mitigated. Studies have shown that Brazil's potential geological storage reservoirs is approximately 2000 Gt (billion tonnes) of CO_2 [6]. Only the Recôncavo Basin indicates a daily consumption of 14.5 kt CO_2/day.

The research and development activities of CCS technologies in Brazil had their beginning in the oil industry, specifically in Petrobras. In this context, it should be mentioned that CO_2 injection tests in fields of the Recôncavo-BA Basin, in the State of Bahia (Northeast Region of Brazil) were initiated in May 1991 in the Buracia field [6]. In Brazil, two institutions stand out in the research and development of CCS technologies, namely the Research and Development Center Leopoldo Américo Miguez de Melo/Petrobras (CENPES) and the Center of Excellence in Research on Carbon Storage/PUC-RS (CEPAC). Regarding the capture of CO_2 emitted by stationary sources, it is also worth mentioning the research activities carried out by the University of Salvador (UNIFACS). Other institutions that support the research and development of CCS technologies in Brazil are: the Brazilian Coal Mineral Association, the Coal Industry Association of Santa Catarina, COPELMI Minerações Ltda, Carvão Network, Ecoar Institute, Instituto Ecoclima, among others.

In the context of the actors/ players that are directly related to CCS technologies in Brazil, it is important to highlight the work that being done by Petrobras. In fact, according to the Inventory of Greenhouse Gas Emissions — base year 2015, prepared by the aforementioned oil company in its sustainability report — Petrobras emissions were 76.9 million tons of CO_2 equivalent — 2.7% less than in 2014. In 2015 Petrobras Sustainability Report [7], the company shows that they evaluate and seek to take opportunities advantage arising from climate change and highlight the following point that they are doing: "research and development of low carbon processes and products, such as technology of capture, carbon dioxide (CO_2) usage and storage, renewable energy, bio-refineries and advanced biofuels" [7]

In the 2017 Sustainability Report [5], Petrobras Company reaffirms that they have been dedicated to managing emissions and climate change the past 15 years, with results in emissions prevented. They were the pioneers in publishing their emission inventories since 2002, and they help to found the Brazilian GHG Protocol program. The company also committed with the issue, because Petrobras mention that they implement processes and projects to ensure that climate change is systematically considered in short, medium, and long-term decision-making [5]

Petrobras (2017) [5] conduct emissions inventory through the SIGEA® ("Sistema de Gestão de Emissões Atmosféricas", i.e., Atmospheric Emissions Management System), which processes monthly information from more than 17,000 sources from 67 typologies. The inventories are submitted annually to third-party verification according to the ISO 14064, and are included in the GHG public registry Protocol. They inventory the greenhouse gases: carbon dioxide — CO_2, methane — CH4 and nitrous oxide — N_2O, in addition to other gases. Between 2016 and 2017, their total greenhouse gases emissions remained stable. In relation to 2014, the emissions of 2017 were 18% lower due to the thermoelectric dispatch reduction, burning in flares reduction, and other operational efficiency measures and divestitures. This reduction in emissions came after a period, started in 2011, when there was an increase in emissions mainly due to the large thermoelectric dispatch during the water shortage that affected the country's hydroelectric generation [5].

In following Figs. 4 and 5, Petrobras (2017) [5], shows the GHG Emission and Emission avoided.

And they focus on the efficiency in the actual process and facilities improvment to CO_2 mitigation:

> "The main initiatives we take to mitigate emissions are related to the better use of gas (reduction of flare burning) and improved efficiency of thermoelectric plants. Currently, the gas used in the exploration and production area (> 95%) is higher

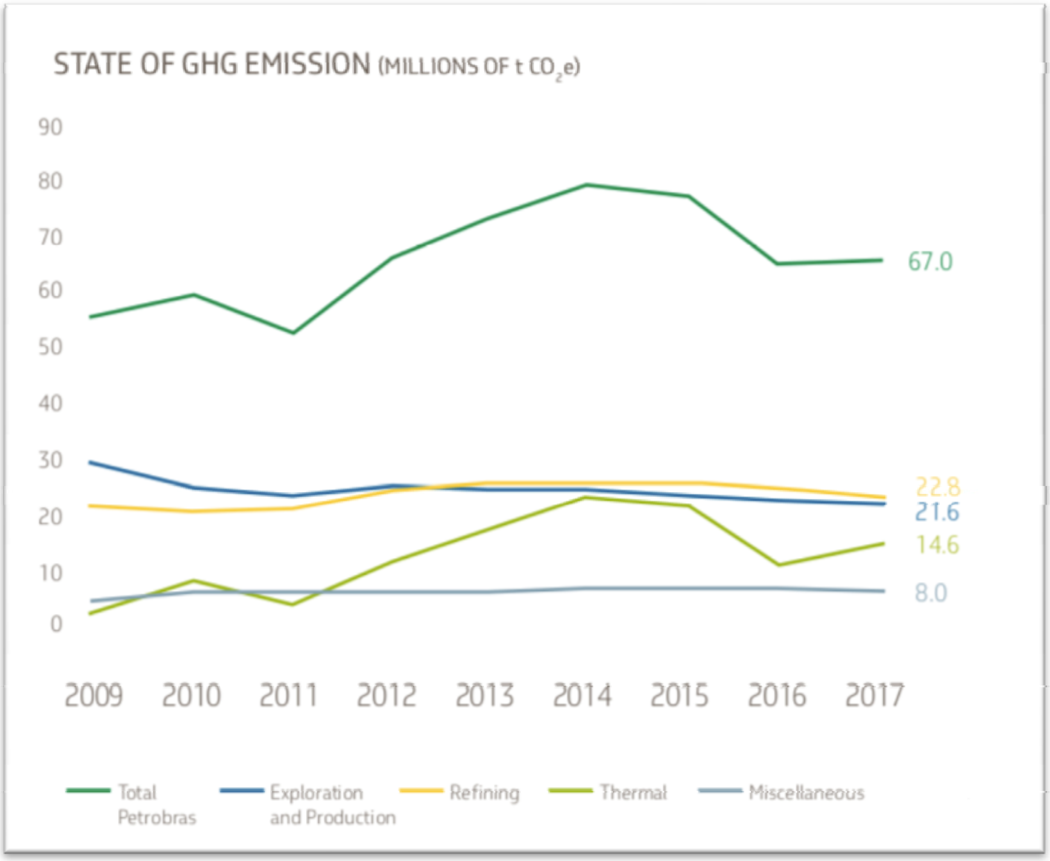

Fig. 4 Petrobras state of GHG emission. Source [5]

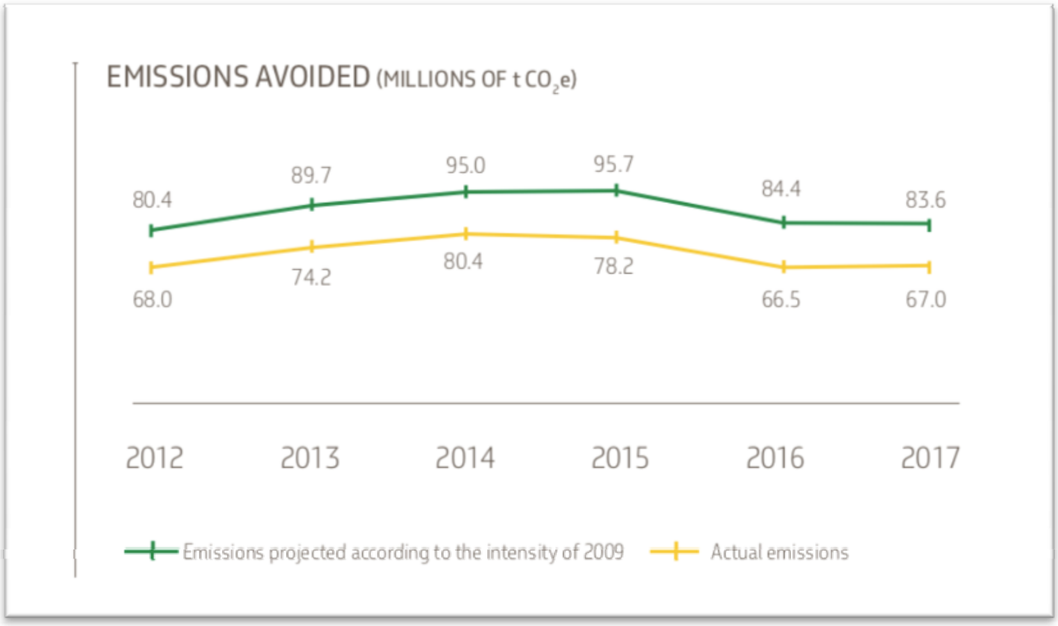

Fig. 5 Petrobras emissions avoided. Source [5]

than the average of the International Oil and Gas Producers Association (IOGP). Our actions also included the modernization of facilities, more efficient equipment, and the standardization of projects and operational practices". (Petrobras, 2017).

In the 2017 Sustainability Report [5] they highlight just in a quote: In 2017 the reinjection of 2.5 million metric tons of separated CO_2 of gas produced in our pre-salt fields in Santos Basin, totalling 7 million metric tons of CO_2 since 2008, including several award-winning technologies (Offshore Technology Conference — OTC [5] but they do not go deeply in this subject and there is no more information about it.

5. Conclusion

Sustainability and climate change are themes that urge for global definitions for human species and other species survive on the planet. CO_2 is one of the main gases that has been emitted and has been increasing its concentration in the atmosphere, contributing even more to the worsening of the global warming. The planet's future odds and temperature rise by more than 2°C within the next few decades challenge large CO_2 emitters to seek alternatives to mitigate or eliminate the usual processes.

The CCS comes as a CO_2 alternative to be captured at all burn fossil fuels and biomass facilities as long as it is a proved large emission source. More than gas capture, the CCS process has also the transport and storage part. However, storage still needs to be studied better. Not focused only in capture, the whole process needs more research and testing investment. Most of the investment comes from the private sector and, in some places, from the government. However, there is a legal risk, because in many countries there are no consistent laws and rules for such action.

There is a lot of CCS potential on all continents, not only the storage capacity, but also the large emitters location history. To an effectively mitigate and reduce greenhouse gas emissions, it is necessary to combine this technology with the effective scale-up of renewable energies and energy efficiency. As stated by the Brazil Government, if there is only the CCS via CDM incentive, for example, the energy matrix will remain polluted by oil and coal; not focusing to the main transformation point, such as renewable energy. In the Brazilian case, Petrobras, the current refineries and the pre-salt are the main CO_2 stationary emitters, which prove that further research need to verify the CCS impact on the current issue. In its official documents, such as Petrobras Sustainability Report, the CCS actions are not explicit, even because the document is all the activities summary of this huge company. To do so, future research would require a deepening of the company's data to verify how much CO_2 is being mitigated with its CCS activities. And, to complete the research, how this issue is being addressed in the areas of financial investment, research and entire process implementation. Finaly, many organizations in Brazil and in the world have been studying the subject, which may be an opportunity for CCS investors and enthusiasts.

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