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Overview of public policies and strategies for the deployment of carbon capture and storage: reflections for Brazil

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Abstract

Objective: To examine which public policies and financing strategies can stimulate the mitigation of GHG emissions through CCS and to reflect on the use of this technology in Brazil.
Methodology: The research approach was qualitative, exploratory and descriptive, based on documental and bibliographic analysis on the subject.
Relevance: Carbon Capture and Storage (CCS) is an emerging technology to reduce greenhouse gases (GHGs) in the atmosphere and thus mitigate climate change. There is a need for government planning to meet Brazil's commitments under the Paris Agreement, in which context the use of CCS can be assessed as a strategy for the country.
Results: The results have shown that the viability of CCS projects is often linked to a strong public policy to support the technology and that it will possibly be dependent on the political will of the government to implement them on a large scale.
Contributions: Analysis of possible approaches to CCS funding in Brazil, also examining possible associations between this technology and some Brazilian sectors, such as oil and gas, bioenergy and cement.
Conclusion: In Brazil, although currently CCS is exclusively associated with the oil and gas sector, this technology can be considered for other sectors as a form of compliance of Brazilian NDCs.

Keywords: Carbon capture and storage. Public policy. Carbon pricing. Green bonds. Climate change.

Panorama das políticas públicas e estratégias para desenvolvimento da captura e armazenamento de carbono: reflexões para o Brasil

Resumo

Objetivo: Examinar quais políticas públicas e estratégias de financiamento podem estimular a mitigação das emissões de GEE por meio do CCS e refletir sobre o uso desta tecnologia pelo Brasil.
Metodologia: A abordagem da pesquisa foi qualitativa, exploratória e descritiva, baseada na análise documental e bibliográfica sobre o tema.
Relevância: A captura e armazenamento de carbono (Carbon Capture and Storage - CCS) é uma tecnologia emergente com a finalidade de reduzir os gases de efeito estufa (GEE) da atmosfera e, assim, mitigar as mudanças climáticas. Existe uma necessidade de planejamento governamental para o cumprimento dos compromissos assumidos pelo Brasil no âmbito do Acordo de Paris, contexto no qual o uso do CCS pode ser avaliado enquanto estratégia para o país.
Resultados: Os resultados mostraram que a viabilidade de projetos de CCS, na maioria das vezes, está atrelada a uma forte política pública de apoio à tecnologia e que, portanto, possivelmente dependerá da vontade política do governo para que sejam implementados em larga escala.

Contribuições: Análise de possíveis caminhos para o financiamento de CCS no Brasil, examinando, também, possíveis associações entre esta tecnologia e alguns setores brasileiros, como petróleo e gás, bioenergia e cimento.
Conclusão: No Brasil, embora atualmente o CCS esteja exclusivamente associado ao setor de petróleo e gás, esta tecnologia pode ser considerada para outros setores como forma de cumprimento das NDCs brasileiras.

Palavras-Chave: Captura e armazenamento de carbono. Políticas públicas. Precificação do carbono. Títulos verdes. Mudanças climáticas.

Panorama de las políticas públicas y estrategias para el desarrollo de la captura y el almacenamiento de carbono: Reflexiones para Brasil

Resumen
Objetivo: Examinar qué políticas públicas y estrategias de financiación pueden estimular la mitigación de las emisiones de GEI mediante la CAC y reflexionar sobre el uso de esta tecnología en Brasil.
Metodología: El enfoque de la investigación fue cualitativo, exploratorio y descriptivo, basado en el análisis documental y bibliográfico sobre el tema.
Relevancia: La Captura y Almacenamiento de Carbono (CAC) es una tecnología emergente para reducir los gases de efecto invernadero (GEI) en la atmósfera y así mitigar el cambio climático. Es necesario que el gobierno planifique el cumplimiento de los compromisos asumidos por Brasil en el marco del Acuerdo de París, en cuyo contexto se puede evaluar el uso de la CAC como estrategia para el país.
Resultados: Los resultados han mostrado que la viabilidad de los proyectos de CAC suele estar vinculada a una política pública fuerte de apoyo a la tecnología y que posiblemente dependerá de la voluntad política del gobierno para implementarlos a gran escala.
Contribuciones: Análisis de los posibles enfoques de la financiación de la CAC en Brasil, examinando también las posibles asociaciones entre esta tecnología y algunos sectores brasileños, como el petróleo y el gas, la bioenergía y el cemento.
Conclusiones: En Brasil, aunque actualmente la CAC se asocia exclusivamente al sector del petróleo y el gas, esta tecnología puede considerarse para otros sectores como forma de cumplimiento de las NDC brasileñas.

Palabras clave: Captura y almacenamiento de carbono. Política pública. Precio del carbono. Bonos verdes. Cambio climático.

Introduction

The current climate crisis requires countries to unite in favor of reducing the emission of greenhouse gases (GHGs) into the atmosphere, which has been increasing the Earth's temperature and the risk of extreme events worldwide (IPCC, 2014). In order to find ways to address the problem of climate change, the most recent agreement signed within the Conference of the Parties (COP), the Paris Agreement, whose elaboration was completed in 2015, aims to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (article 2, paragraph 1 (a) of the Paris Agreement). Moreover, the conscientization about the importance of financial flows following pathways consistent with GHG reductions is one of the efforts that need to be made, according to the Agreement (article 2, paragraph 1 (c) of the Paris Agreement).

Among the strategies for GHG mitigation, those aimed at removing carbon dioxide (CO_2) from the atmosphere are investigated in various scenarios built to achieve the goal of limiting the increase in temperature. Some examples of approaches that have such a characteristic are: afforestation and reforestation; soil carbon sequestration; ocean alkalinization; and carbon capture and storage in geological formations (CCS) (IPCC, 2018). The use of CCS for climate mitigation, whether associated with bioenergy production (BECCS) or other CO_2-emitting processes (industrial or energy production), has a significant potential to remove large amounts of CO_2 from the atmosphere (IPCC, 2018; Global CCS Institute, 2019).

In that context, CCS has been mainly considered for its integration in energy systems (associated with sources such as oil, natural gas and bioenergy), but there are also studies and projects for the decarbonization of industrial sectors, such as cement, oil refining, iron and steel (Bui et al., 2018). The use of CCS in association with biofuel is in turn relevant for the generation of negative GHG emissions (e. g. Cox; Edwards, 2019; Moreira et al. 2016).

One of the periods when CCS technology was most prominent occurred precisely after the release of the Intergovernmental Panel on Climate Change (IPCC) report in 2005, when there was a promise of public investment of $30 billion and a commitment made by G8 countries to build 20 large-scale CCS projects. However, due to political difficulties, complexity, and unanticipated costs related to the development of this technology, a much smaller amount than promised was invested ($2.8 billion, between 2007 and 2014) (Ogihara, 2018). Although support for CCS, especially in the financial level, has not gone as planned in this period, interest in the technology has regained momentum after the 2018 IPCC report (IPCC, 2018).

One of the most challenging stages for CCS projects is fundraising and investment, given, for example, the high volatility and uncertainty in the face of legal, fiscal, and economical scenarios (Herzog, 2017; Ereira, 2010). The challenge is even greater in developing countries, so there are few CCS projects in Africa, Asia, and Latin America, mainly because there are no significant sources of carbon funding or expectation of profiting from CCS (Almendra et al., 2011).

Thus, in face of the CSS projects' potential to combat climate crisis and the difficulties in funding this technology, the objective of this paper is to analyze which public policies and financing strategies could stimulate the mitigation of GHG emissions through CCS, while also reflecting on the use of the technology in Brazil. To this end, in the second section of the paper, the technology will be presented and Brazilian experiences with CCS will be exposed. In the third section, some instruments that could facilitate the funding of CCS will be described. The fourth section will discuss GHG emissions in Brazil and highlight the Brazilian commitments and those of some companies to combat climate change. After addressing all these points, the fifth section will be dedicated to evaluate some sectors in which those technologies could be introduced and discuss the need for Brazil to adopt a clear position on their use.

Carbon capture and storage status in the world and in Brazil

The IPCC defines "Carbon Dioxide Capture, Transport and Storage" as a process consisting of the separation of Carbon Dioxide from industrial and power generation sources, its transport to storage sites, and its long-term isolation from the atmosphere (IPCC, 2005).

The storage of CO_2 can be done via some known and developed technological options, which are basically three: storage on deep ocean floor, mineral carbonation, and storage in geological reservoirs (IPCC, 2005). Currently, geological storage stands out, since it is a technology that's already mastered and in use on a large scale.

Injecting CO_2 into a geological reservoir is a process that has been used in some industries. There are available technologies in the petroleum industry for enhanced oil or gas recovery using the injection chemicals, including CO_2. According to the IPCC (2005), the main options for geological storage of CO_2 are: injection into depleted (depleted) oil and gas reservoirs; the use of CO_2 for enhanced oil or gas recovery (EOR and EGR); CO_2 injection into unused deep saturated reservoirs of saline waters; injection into deep layers of untapped mineral coal; the use of CO_2 in enhanced coal bed methane recovery (ECBM); and storage other suggested options – basaltic formations, oil shale and caves.

Some of the technologies mentioned, such as enhanced oil recovery (EOR), enhanced natural gas recovery (EGR), and enhanced coal bed methane recovery (ECBM), add value to CO_2 storage in geological reservoirs; the injected CO_2 is used to increase the production of oil, gas, or methane, respectively, in addition to simple storage. The other storage options do not add value; storage is performed only for the purpose of storing the CO_2 and preventing its emission into the atmosphere (APEC, 2005).

According to Meadowcroft and Langhelle (2009), there was a push towards CCS technology by the International Energy Agency (IEA) in the early 1990s, due to the creation of the Greenhouse Gas Research and Development Program. At that time, active international networks of industry, academy, and government promoted the comprehension of CCS (Meadowcroft and Langhelle, 2009).

The importance of CCS as one of the main technologies available for the purpose of mitigating/reducing CO_2 in the atmosphere has been highlighted by the Intergovernmental Panel on Climate Change (IPCC, 2018, p. 15):

> Such reductions can be achieved through combinations of new and existing technologies and practices, including electrification, hydrogen, sustainable bio-based feedstocks, product substitution, and carbon capture, utilization and storage (CCUS). These options are technically proven at various scales but their large-scale deployment may be limited by economic, financial, human capacity and institutional constraints in specific contexts, and specific characteristics of large-scale industrial installations.

It is important to highlight some conceptual differences that are currently being adopted due to the use of CO_2, in regards to adding economical value to a project. In addition to the term CCS, the terms CCUS (Carbon dioxide Capture, Use and Storage) and CCU (Carbon dioxide Capture and Use) have also been employed. According to the conceptualization given by Hasan et al. (2015):

> While most studies considered CCS or CCUS activities, few considered the capture and utilization of CO_2 at the same time. In this work, we introduce the concept of a CO_2 capture and utilization (CCU) supply chain network to capture CO_2 from the source plants, and utilize the anthropogenic CO_2 for enhanced oil recovery purposes. While the goal of a CCUS supply chain network is to reduce the CO_2 emissions, the goal of a CCU supply chain network is to maximize the revenue or profit from CO_2 utilization. Therefore, the CCU supply chains are driven by economic drivers, whereas the CCUS supply chains are primarily motivated by the environmental benefits through reducing emissions.

According to the National Energy Technology Laboratory (NETL)'s CCS database[1] as of April 2018, there were 305 CCS projects worldwide, with 299 sites identified. The 299 projects whose sites were identified include 76 capture projects, 76 storage projects, and 147 capture and storage projects, in over 30 countries of the 6 continents. While several projects are still in the planning and development stages and many have been completed, 37 are actively capturing and/or injecting CO_2.

Initiatives for mastering CCS technologies in Brazil began in the 1990s, especially in the oil industry, with Petrobras. According to Lino (2005), CO_2 injection tests in fields of the Recôncavo Basin/BA started in May 1991 in the Buracica field.

In 2011, Beck et al. (2011) highlighted that there were a few demonstration projects in Brazil, two of which were from Petrobras: the project in Miranga and the Porto Batista Carbomethane Project, with CEPAC. The Petrobras Miranga Project had three different storage scenarios: EOR, depleted gas reservoir, and saline aquifer. The CEPAC Porto Batista Carbomethane Project was developed to watch over the enhanced coal bed methane (ECBM) production.

Brazil is currently home to one of the largest CCS-EOR projects in the world, the Lula field project in the pre-salt oil province. According to the Global CCS Institute, in its database (CO_2RE)[2]:

> Since 2011, Petrobras has developed CO2 separation and injection systems installed in eight FPSO's for the production of O&G fields located in the offshore Santos Basin Pre-Salt. The CO2 associated with the natural gas is separated then compressed and injected on gas injection wells for enhanced oil recovery. As of June 2021, the Santos Basin Pre-Salt development reached the milestone of 21.4 million tons of CO2 injected cumulatively, with 7 million tonnes injected in 2020. The project's ambition is to inject a total of 40 million tonnes of CO2 by 2025, contributing to the technological evolution, cost reduction, and demonstration of the safety of the CCUS technology.

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[1] https://netl.doe.gov/coal/carbon-storage/worldwide-ccs-database (access November 21st, 2020).
[2] https://co2re.co/StorageData (access November 21st, 2020).

Mechanisms for funding CCS and CCUS

There are several mechanisms that can help fund CCS projects, and some of them have already been used in large demonstration projects of this technology. In this paper, we use the classification defined by Herzog (2017), which considers the following groups of mechanisms: market pull; technology push; regulatory driver; and business driver.

Market pull

Market pulls are mechanisms that already exist in the market, which can be used to help fund the technology. Some examples are: carbon markets, electricity markets, and EOR. Other uses currently being studied for CO_2 (CCU) could be added to this list, such as industrial feedstock or component for the creation of synthetic fuels (Quarton; Samsatli, 2020).

Carbon markets are counters where carbon credits are traded, and those exchanges can be made in regulated or voluntary markets. The regulated market was established with the Kyoto Protocol in order to correct negative market externalities arising from GHG emissions that impact all of society (Souza et al. 2013). In this market, companies and countries can offset emissions that exceed what was previously defined in agreements or regulations. The voluntary market, by its turn, is primarily inspired by corporate compliance, with companies and individuals voluntarily offsetting GHG emissions (Guigon, 2010). Thus, if CCS projects access carbon markets, they may be able to finance at least part of the project by selling the carbon credits that can be obtained from CO_2 storage. According to the United Nations Development Programme (UNDP, 2016, p. 1), carbon markets can collaborate to combat climate change in the following ways:

> Carbon markets aim to reduce greenhouse gas (GHG, or “carbon”) emissions cost-effectively by setting limits on emissions and enabling the trading of emission units, which are instruments representing emission reductions. Trading enables entities that can reduce emissions at lower cost to be paid to do so by higher-cost emitters, thus lowering the economic cost of reducing emissions.

The electricity market, in turn, as a market pull, is so called when there is an offset of business costs (in this case, the implementation of CCS), which will be passed on to those who pay for the fee. Access to this market depends on a special permission from the electricity market regulators, or a special law or regulation (Herzog, 2017).

In the case of EOR and CCU, the impetus for carbon capture projects would exist due to the commercial value of CO_2 itself. That value may encourage, for example, carbon capture projects in polluting units, with some or all of the project costs being compensated by selling the CO_2. However, it is worth noting that for EOR to be considered an incentive for CCS, after CO_2 is used for oil extraction, it cannot be vented, i.e., it must be stored, so that it does not act as a greenhouse gas. Similarly, CCU projects are considered climate change mitigating if the use of CO_2 prevents it from returning to the atmosphere.

Technology push

Governmental programs can provide the necessary incentive for an emerging technology to develop, unlike a commercial technology, whose funding comes entirely from the market (Herzog, 2017). Among those technology incentives are direct subsidies, tax credits, and loan guarantees (Herzog, 2017). Because of the need of large investments for their development, "technology pushes" have played an important role in leveraging private investment in large-scale CCS projects (Ogihara, 2018).

Tax incentive programs can have a great impact on CCS development. An example of recent legislation in this regard is Section 45Q passed in the United States, which was revised in 2018. Section 45Q defined the granting of tax credits in the amount of $35 per metric ton of CO_2 used in enhanced oil recovery (EOR) and $50 per metric ton of CO_2 stored in geological formations. Credits of $35 will also be awarded for CO_2 utilization projects not related to EOR and projects to capture CO_2 directly from the air (U.S. Department of Energy, 2019). Interest in CCS has increased significantly since the value of the credits was increased, causing power sector companies to revise business plans to insert the possibility of implementing CCS (Esposito et al. 2019).

Funds created specifically for financing technology or that place CCUS as one of the funding possibilities are also very important in project implementation. Some examples of funds that have financed CCS projects are: the Alberta CCS Fund and the Canadian Clean Energy Fund, which funded the operations of the Quest CCS Project in Canada; and the US Clean Coal Power Initiative fund, which provided funding for the Kemper County IGCC, Petra Nova, and Illinois Industrial projects (Ogihara, 2018).

International funds targeting developing countries can contribute to the implementation of CCS projects in those countries. The Green Climate Fund (GCF) is an example of this type of fund, having been created by the UNFCCC to combat climate change in developing countries (Ogihara, 2018).

Another relevant tool for the discussion about the funding of CCS projects, which is not mentioned by Herzog (2017), but which would work as an incentive for technology, is the use of green bonds. The aim of these bonds is to encourage traditional debt markets to assist more significantly in financing projects that contribute to sustainable development (ICMA, 2020a). As the demand by institutional investors and the market for investments that mitigate negative climate impacts grows, the search for sustainable projects and opportunities has raised the need for a methodology to assess and certify the actual sustainability of projects (ICMA, 2020a), allowing climate change risks to be properly incorporated into the pricing of invested assets.

In this form of funding, any capital market issuer, under applicable regulations and legislation, can issue a green bond to fund a sustainable project, as long as it is aligned with the pillars of the *Green Bonds Principles* (GBP) (ICMA, 2020a). The GBP emerged as an initiative of the *International Capital Market Association* to provide guidelines in the process of issuing green bonds, recommending transparency and some guidelines that promote integrity in the development of the green bond market and clarifying the approach to their issue (ICMA, 2018).

Thus, CCS projects can benefit from this investment model, provided that they can be proven to generate a positive environmental externality and that they are aligned with the GBP. To do so, they need to be audited by one of the corporations accredited as certifiers by the Green Bonds Initiative (ICMA, 2020b). As the GBP only suggests which categories of projects can be considered as Green, issuers are encouraged to use benchmarks and create or use taxonomies as a reference in the issuance process (HIRSCH, 2019, ICMA, 2020a).

Some taxonomies have emerged as references in recent years, including the Climate Bond Initiative, which since 2013 has been consolidating the best practices in the control, evaluation, verification and certification of projects that want to be financed through green bonds (CBI, 2020a). Besides that, the EU Taxonomy, developed by the Technical Expert Group on Sustainable Finance of the European Commission, was created to guide the issuance of green bonds in the European Union (EU), directing the identification and evaluation of projects and assets that contribute to the reduction of GHG emissions and are aligned with criteria consistent with the goal of reducing 2°C by 2050, defined by COP 21 (European Commission, 2020).

The certification of CCS projects as Green under these two taxonomies is controversial and remains in a grey area, with several institutions requiring extra analysis to mitigate the risks associated with greenwashing (Beder, 2014). The Climate Bonds Initiative, for example, does not certify as Green any CCS projects associated with fossil fuel power generation, but accepts CCS projects associated with biofuel power generation (CBI, 2020b).

The EU Taxonomy, in turn, considers several uses of CCS in some types of projects: water supply; sewage system; waste management and remediation activities. However, it also shows that it needs further research to improve the certification of CCS projects related to power generation and transmission (European Commission, 2020).

Other taxonomies, developed by Asian banks and private players, consider CCS to be eligible for funding through green bonds (CBI, 2019; Bachelet, Becchetti, Manfredonia, 2019), demonstrating that financing these projects through such a model is possible, but requires extensive research and development of a clear and consistent taxonomy aligned with GBP.

Mechanisms for funding CCS through green debt intake in Brazil are no different; it is essential, however, that a national or South American taxonomy be developed, one that allows issuers to certify sustainable projects. That could be the key to lever such projects.

Regulatory driver

Climate-based regulations are among those that have the most impact on CCS funding. Those regulations can stimulate the technology directly or indirectly.

Among the regulations that can indirectly fund CCS is carbon pricing through taxation. This can be comprehensive, for all economic sectors, or targeted at a specific segment of the economy. In the first case, a tax is levied per amount of CO_2 emitted, offering flexibility for emitters to choose their emission reduction strategies and for governments to increase or decrease the tax depending on the need to adjust the emissions of the country or region (Valentine, Brown, and Sovacool, 2019). Instead of setting a tax for all CO_2 emissions, the government can also set an emissions cap, called a Carbon cap, in which the tax would be levied for the amount that exceeds the cap (Valentine, Brown, and Sovacool, 2019).

In the second case, regulation occurs for a specific sector, which is something that could unintentionally distort markets (Valentine, Brown, and Sovacool, 2019). One example of sector-specific carbon pricing is the case of Norway, which has a tax for CO_2 from offshore oil and gas production, which ultimately incentivized investment in CCS projects in Sleipner and Snøhvit (Ogihara, 2018).

Another example of specific regulation is the Canadian emissions standard directed at new or end-of-life coal plants, which states that these plants must achieve "a performance standard fixed at 420 tonnes of carbon dioxide per gigawatt hour ($t\ GWh^{-1}$) to allow continued operation while emissions exceeding 370 $t\ GWh^{-1}$ would be subject to a carbon tax which would increase to $50 per tonne by 2022" (Giannaris et al., 2020, p. 2).

Business driver

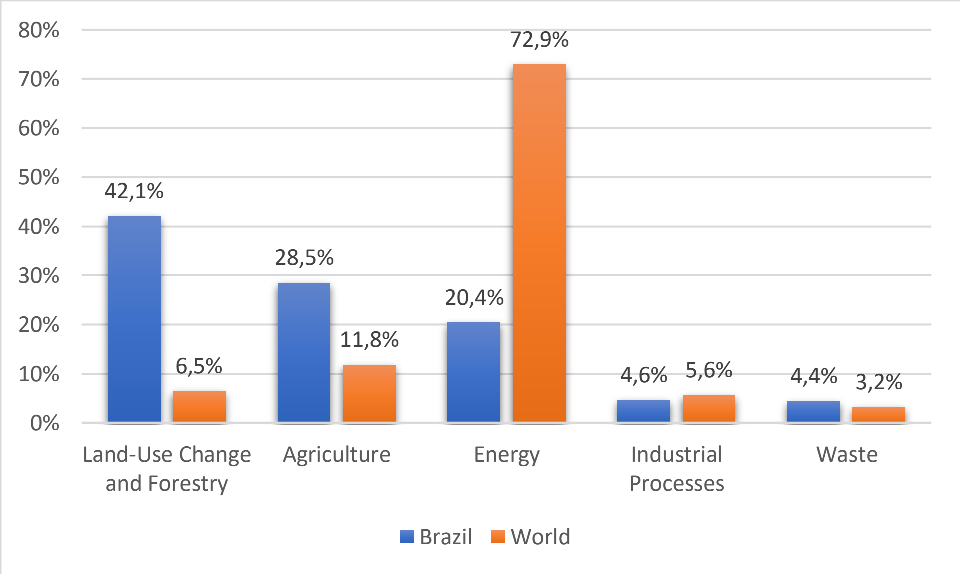
CCS can be stimulated by "business drivers" when there is a persuasive business case that has an alignment with technology (Herzog, 2017). In this regard, many companies have been motivated to create plans to reduce their own GHG emissions in order to be recognized as sustainable. Thus, if those companies' strategic plans include the insertion of CCS or CCUS as a technology that makes up the portfolio of actions aimed at sustainability, the company's plan will work as a business driver.

Greenhouse gas emissions and the commitments of Brazil and Brazilian companies to climate change

In order to inventory GHG emissions worldwide, the IPCC standardized and classified potentially emitting activities into the following sectors: Energy, Industrial Processes, Agriculture, Land-use change and forestry, and Waste (IPCC, 2006). When comparing the most representative sectors according to the world average and the most representative sectors in Brazil, there is a significant difference (see figure 1).

Table 1

Comparison between GHG emitting sectors in Brazil and worldwide (2016)



Source: Elaborated by the authors based on SEEG (2020) and Climate Watch (2020).

As figure 1 shows, in Brazil, the sector that contributed the most to GHG emissions was "Land-use change and forestry", with approximately 44% of the total emissions in 2018 (SEEG, 2020). The world average for this same sector in 2016, by the other hand, accounted for only 6.5% of total emissions. The high emissions in the "Land-use change and forestry" sector in Brazil are mainly the result of deforestation dynamics in the Amazon and Cerrado biomes (SEEG, 2020).

On the world average, the energy sector was incomparably the one that contributed the most to GHG emissions, corresponding to 72.9% of the emitted GHG. This occurs because the world energy matrix is formed mostly by fossil sources (84.3%): oil (33.1%), coal (27.0%) and natural gas (24.2%) (BP, 2020). In Brazil, although fossil sources also correspond to the majority of the matrix, they represent proportionally less (53.9%): oil and oil products (34.4%), mineral coal (5.8%), natural gas (12.5%) (EPE, 2020). Even so, Petrobras, the Brazilian state-owned oil and natural gas exploration company, ranks twentieth among the oil, natural gas,

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and coal exploration companies that most emitted CO_2 between the years 1965 and 2017 in the world, with the top 20 companies in this ranking accounting for approximately 35% of global GHG emissions in this period (HEEGE, 2018).

The commitment made by Brazil when ratifying the Paris Agreement in September 2016, through the Nationally Determined Contribution (NDC)[3], provides quantitative climate change mitigation goals for the years 2025 and 2030. In the year the Paris Agreement was signed, Brazil already showed a reduction of approximately 24% in relation to the reference year (2005). However, between 2016 and 2019, total GHG emissions increased by about 4.5% in the country (SEEG, 2020), which left the goal even farther away, with a reduction of only about 17% in relation to the base year.

To achieve these GHG reduction goals, Brazil explored the following contributions in the NDCs presented in 2016: in regards to the Brazilian energy matrix, it stated it intends to increase the share of sustainable bioenergy; in regards to the land-use change and forestry sector, it focused on measures such as reducing deforestation, restoration and reforestation; in regards to the energy sector, it mentioned the expansion of renewable energy and energy efficiency gains; in regards to the agricultural sector, it considered the development of sustainable agriculture; in regards to the industrial sector, it focused on energy efficiency measures, promotion of clean technologies, and low-carbon infrastructure; in regards to the transport sector, it cited efficiency measures and infrastructure improvement (Brasil, 2016).

It is worth noting that, among the measures aimed at removing CO_2 from the atmosphere, the only ones directly contemplated by the Brazilian NDC are restoration and reforestation. In the energy sector, there is no mention of technologies that capture GHG emissions from fossil fuel energy, such as CCUS, or BECCS. In the industrial sector, in turn, since the mentioned measures are quite broad, the use of CCUS could be fit for GHG reduction.

Companies also play a key role in combating climate change, so without their commitment to reduce GHG in their businesses, it will be difficult to achieve global reduction goals. It is estimated, for example, that about 71% of GHG emissions between the years 1988 and 2015 stemmed from the activities of the 100 largest fossil fuel producing companies (CPD, 2017).

In this sense, in order to contribute to the knowledge about GHG emitted in the Brazilian territory, many Brazilian companies disclose their GHG emissions inventories. In 2019, 156 organizations, members of the Brazilian GHG Protocol Program, released inventories (148 complete and 8 partial), and together they represent 14.8% of national emissions (scope 1) and 14% of the national grid electricity consumption (scope 2) (FGVces, 2020). Three of those

[3] Reducing greenhouse gas emissions by 37% below 2005 levels in 2025, and reducing greenhouse gas emissions by 43% below 2005 levels in 2030 (BRAZIL, 2016).

companies that have published GHG inventories will be discussed below; they were chosen because they are in sectors that traditionally emit high levels of GHGs: Petrobras (largest fossil fuel company in Brazil), Vale (largest Brazilian mining company), and Votorantim Cimentos (largest cement producer in Brazil).

According to the GHG inventory presented, Petrobras emitted 59 million t CO_2-eq in 2019, considering scopes 1 and 2 (Petrobras, 2020). In addition to presenting the GHG inventory, Petrobras also participates in the *Oil and Gas Climate Initiative* (OGCI), a consortium of oil and gas companies that aims to accelerate the industry's response to climate change. The members have committed to collectively invest more than $1 billion in solutions to decarbonize the oil and gas sector, as well as the industrial and transport sectors. Within the OGCI's portfolio, there are 7 projects focused on CO_2 capture, storage or use (OGCI, 2020). Furthermore, among the 10 commitments to sustainability published in Petrobras' strategic plan, there is a proposal of reinjecting approximately 40 MM tons of CO_2 by 2025 in CCUS projects (Petrobras, 2020).

The mining company Vale, by its turn, emitted 12.6 million t CO_2-eq in 2019, considering scopes 1 and 2 (Vale, 2020). Vale has an ambitious commitment to become carbon-neutral in its operations (scopes 1 and 2) by 2050. Other commitments related to climate change are the following: adoption of a shadow carbon price of US$ 50 per ton of CO_2 equivalent, to be used in economic feasibility studies for projects; and adoption of a shadow carbon price of US$ 10 per ton of CO_2 equivalent, for carbon sequestration in forest restoration and reforestation projects. Vale's social and environmental targets in Agenda 2030 include: the recovery and protection of 500,000 hectares of degraded areas beyond our borders, and 100% self-production of clean energy globally. There is no mention of CCS or CCUS projects in the sustainability report published by Vale in 2019 (Vale, 2020).

Votorantim Cimentos, one of the largest companies in the construction materials sector in the world and part of the Votorantim S.A. group, was responsible for the emission of approximately 19.9 million t CO_2-eq in scope 1 and 2 of its operations[4], in 2019 (Votorantim, 2020). The company aims to reduce the intensity of emissions per ton of cement by 25% by 2020 compared to 1990. In addition, Votorantim Cimentos aims to reduce the use of fossil fuels in its cement plants, reaching a rate of 30% of non-fossil fuels. Due to the company's initiatives aimed at sustainability, in 2019 it could contract a revolving credit line, called *Sustainable Committed Credit Facility*, with provisions tied to sustainability indicators and with a variable rate to be defined according to the company's performance indicators based on sustainability targets. The price of carbon is also being considered for the feasibility analysis of projects in the company (Votorantim, 2020).

[4] Scope 1 emissions cover the operations in Brazil and from VCNA Cements, VCEAA and VCLatam, based on a consolidation approach.

There is a tendency that more and more companies, in addition to publishing their GHG emissions inventories, present GHG reduction targets and other sustainability-oriented projects. The trend towards carbon pricing is also being considered by many companies for the analysis of future projects. In this context, it is important that companies study the possibility of including the investment in CCS in their portfolio of projects.

Reflections about the development of the CCS in Brazil

Brazilian sectors that could benefit from the use of CCS

Brazil has the potential to develop and implement CCS projects in several sectors. Among those that could consider investing in this technology in Brazil are the energy sector (with BECCS and/or oil and natural gas) and the industrial sector.

The oil and gas sector is the one most associated with CCS, and this observation is also true for Brazil, whose largest project features the injection of CO_2 into the pre-salt Lula field for enhanced oil recovery (EOR) from the processing of natural gas extracted from the same field. Although this is one of the most common arrangements, there are disagreements about the classification of CCS-EOR projects as sustainable. For example, while the United States, through Section 45Q, is helping to finance CCS-EOR projects by providing tax credits worth $35 per metric ton of CO_2 stored, the Climate Bonds Initiative, in its taxonomy, understands that oil extraction projects are incompatible with the issuance of green bonds (CBI, 2020a).

This sector, which is of great relevance to Brazil's energy security, is also one of the biggest contributors to the increase of GHG in the atmosphere worldwide. However, although alternatives are being considered for the substitution of these sources, such as the use of electric cars and the introduction of hydrogen in the energy matrix, the energy transition will not be immediate and it will take years, possibly decades, for it to be complete. In particular, with respect to natural gas, it is projected that this source will play a major role in securing energy flows, assisting in the development of renewable energy (Valentine, Brown and Sovacool, 2019). Thus, even if there is already a projected reduction in the use of oil and natural gas in the future, CCS projects associated with this sector could mainly be evaluated for the energy transition period, for a more immediate emission reduction by the sector.

In that context, green transition bonds could arise, or government policies aimed at the short and medium term for the sector (with taxes, subsidies or specific regulations). Brazil could, for example, be inspired by the Canadian policy for the coal sector, which treats emissions from new coal plants or those that have reached the end of their useful life more strictly. In addition, part or all of the funding for CCS projects linked to the oil and gas sector could come from the sector itself, as a way to reduce GHG emissions, improving the sustainability of its business. Petrobras, as previously mentioned, already invests in CCS, although the investment is restricted to the association of CCS with EOR, something that could be expanded by the company.

Moreover, the association of bioenergy with CCS – BECCS – is cited by several academics (e.g. Cox and Edwards, 2019; Moreira et al., 2016) and by the IPCC (IPCC, 2018) as one of the solutions for the mitigation of climate change, on the grounds that the project results in negative emissions. However, considering that the bioenergy sector is among the sources of low GHG emissions and that there is already support for its development, for the country to achieve a cleaner matrix (as stated in the Brazilian NDC), there is no incentive for the sector itself to invest in BECCS, unless there is financial compensation for it, unlike the oil and gas sector, in which there is an international pressure for the use of these sources to be reduced or for less GHGs to be emitted in the production processes. For this reason, it is believed that for BECCS to be developed in Brazil on a large scale, the government would need to strongly encourage those projects, or the price of carbon would have to be more attractive.

In Brazil, one of the main possibilities for BECCS is its use in the production of ethanol, which comes from sugarcane. It is estimated that it would currently be possible to eliminate 27.7 million tons of CO_2 from sugarcane fermentation, which corresponds to approximately 5% of the country's energy production emissions (Moreira, 2016). Moreira et al. (2016) bring the following policies as possibilities for financing BECCS: sharing the cost of ethanol fuel and bioelectricity with consumers of this fuel; sharing the cost of ethanol fuel and bioelectricity with all consumers of light-duty car fuel and electricity; subsidizing bioenergy producers (defining a price for carbon); and tax moratorium of prices that rise as a result of the BECCS. In addition to these policies, issuing green bonds and financing projects (at least pilot projects) through climate funds are also alternatives for financing the technology. According to Cox and Edwards (2019), for negative emissions technologies, having a diversity of policies concurrently stimulating the technology could be an alternative for its development.

The industrial sector is also a possible candidate for developing CCS projects, especially when there is a difficulty in replacing the production process of some input by another one with less CO_2 emissions, as is the case of the cement industry (Bui et al., 2018). The cement production sector accounts for approximately 5% of global CO_2 emissions (IEA, 2020), making it a key industry in decreasing GHGs. While there is a challenge of maintaining the competitiveness of companies with increasing costs for decreasing CO_2 emissions (Bui et al. 2018), at the same time there is pressure, including from investors, for those companies to make their part in combating climate change. For this reason, several companies have already presented plans to reduce emissions, as is the case of Votorantim Cimentos company, previously mentioned. Thus, although CCS is not within the company's portfolio of solutions, this may in the future be a project designed for the company, depending on Brazilian and international public policies, and may even be partially funded by the company itself.

For the large-scale adoption of CCS in Brazil, some barriers would need to be surpassed. Some of them are the lack of government incentives, the high cost of the technology, the slowness with which new materials move from the laboratory stage to the pilot project scale, the difficulty in monitoring storage (Bui et al. 2018), and the possibility of rejection of the technology by the population (Netto et al., 2020), among others. However, although barriers exist, they are not insurmountable, especially if there is government interest in developing the technology.

Adoption of a stance on CCS by the Brazilian government

Brazil's NDCs, submitted in 2016, while indicating the desired emission reduction targets for 2025 and 2030 (37% and 43%, respectively, with respect to 2005 emissions), did not signal in a broad way the effective measures that will need to be taken for the goals to be actually met (Brazil, 2016). In turn, the subsequent NDCs, presented in 2020, were even more omissive regarding sectoral goals and the means to achieve them (Brazil, 2020). Therefore, a more concrete planning is needed to achieve the emission reduction targets established in the Brazilian NDCs, so that within this context the CCS can be considered, or not, as part of the country's strategy.

In regards to a stance on CCS and a definition of in which sector would the technology be more viable, Brazil could follow the example of the European Union and create a taxonomy that specifies in which contexts CCS could be considered a sustainable project. A clearer and more consistent stance could bring security to investors and companies that consider the investment in CCS but may be afraid to adopt a technology that will not receive the country’s support.

It should be stressed that what is being proposed in this paper is that the Brazilian government adopts a stance and define what are the priority measures for complying with the NDCs, and not necessarily that CCS be defined as one of those measures. There are several alternatives for the mitigation of climate change and they need to be taken into account for the definition of Brazilian climate governance.

One of those alternatives for compliance with the NDCs would be to focus on the sector that has contributed the most to Brazilian emissions, "Land-use change and forestry", especially as a result of the increase in deforestation in the Amazon forest. Moreover, internationally, there is pressure for Brazil to direct efforts towards the preservation of the Amazon, which has intensified with the fires that occurred in 2020 (Stuenkel, 2020). Therefore, there is an urgency for the country to prioritize measures to combat deforestation, as well as consider measures such as reforestation, which can play an important role in annual emission reductions and bring positive effects for biodiversity (Kerdan, Giorola, and Hawkes, 2019).

On the other hand, one must evaluate the costs related to CCS as opposed to other available GHG reduction options. There are many studies whose results show that meeting GHG reduction targets would be less costly in scenarios where CCS is applied on a large scale (Bui et al., 2018). It is worth noting that the development of carbon capture and storage technology may also provide opportunities for future use of CO_2 as an input for applications such as mineralization, biological use, food and beverage, energy storage media, and chemical processes (Zhang et al. 2020). If CO_2 comes to have a relevant commercial value in the future, mastering CO_2 capture technology may help to boost Brazil's development.

In fact, those two strategies for GHG mitigation are possible and not necessarily mutually exclusive. Brazil, however, needs to define a stance in relation to these and other various existing alternatives, through planning for compliance with its NDCs.

Conclusion

A plan for the mitigation of GHG emissions needs to be urgently discussed by the Brazilian government in compliance with the Paris Agreement, of which Brazil is a signatory. If global emissions continue to rise, the climate crisis will worsen, and the measures needed to control it will have to be even more intense and costly. Given this scenario, this paper discussed possible public policies and strategies for funding the development of carbon capture and storage as an alternative for mitigating climate change.

As could be seen throughout the paper, the viability of CCS projects, in most cases, is linked to a strong public policy to support the technology, which can be done through CO_2 taxation, subsidies, financing funds and specific regulations, among other alternatives. Furthermore, the possibility of issuing green bonds for CCS projects was discussed and, although it is still in a grey area, it is seen as an option to facilitate financing.

In Brazil, CCS could be used in several sectors, some of the most promising being: the oil and gas sector, in order to mitigate its emissions in the energy transition period, a time when the sector will still be essential for maintaining the country's energy security; the bioenergy sector with the BECCS, which has relevance due to negative emissions; and the industrial sector, as a way to mitigate emissions that would otherwise be difficult to solve. However, for the use of this technology to become widespread, it has to be a part of the government's planning to comply with the NDCs, which is still far from what is necessary. Brazil has the potential to become a model country in issues related to sustainability, a role that for years was nurtured and that can be resumed, provided that more decisive measures are taken by the current and future governments.

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