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REGULAMENTAÇÃO SOBRE ARMAZENAMENTO GEOLÓGICO DE CO_2 NO BRASIL

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RESUMO

A tecnologia de captura e armazenamento de carbono (CCS) tem recebido muita atenção desde os anos 1990, pois foi escolhida como uma opção para mitigar a mudança climática. Os marcos legais e regulatórios necessários para o amplo desenvolvimento dessa tecnologia são considerados incipientes na maioria dos países, como no Brasil. Este estudo mostrou que o Brasil não possui leis específicas para a regulação do CCS. Pôde-se concluir que o Brasil pode se basear na regulamentação existente na indústria de mineração e petróleo para desenvolver uma regulamentação específica sobre CCS. Foi possível observar, com base nas regulamentações vigentes no Reino Unido, UE, Dinamarca, Austrália, EUA e no Canadá, que para a regulamentação ser efetiva, considerar fatores como a clareza e a eficiência do processo administrativo de solicitação para aprovação de projetos de CCS e responsabilidade de longo prazo para fechamento, monitoramento e liberações acidentais de CO2 é essencial.

PALAVRAS-CHAVE: mudança climática, CCS, regulamentação, mineração e petróleo

REGULATION OF THE GEOLOGICAL STORAGE OF CARBON DIOXIDE IN BRAZIL

ABSTRACT

Carbon capture and storage (CCS) technology has been receiving a lot of attention since the 1990s because it has been chosen as an option for mitigating climate change. The legal and regulatory frameworks necessary for the broad development of this technology are considered incipient in most countries, as in Brazil. This study showed that Brazil doesn't have specific laws for the regulation of CCS. It can be concluded that Brazil can build on existing regulation in the mining and oil industry to develop a specific regulation on CCS. It was possible to observe, based on the existing regulations in the U.K., the E.U., Denmark, Australia, the USA, and Canada, that for regulation to be effective, consideration of factors such as clarity and efficiency of the administrative process of applying for and obtaining approval for CCS projects and long-term liability for closure, monitoring, and accidental releases of CO2 is essential.

KEYWORDS: Climate change, CCS, Regulation, oil and mining industry.

1. INTRODUCTION

Climate change, the search for cleaner energy sources, and energy efficiency have become the focus of major world political meetings since the 1990s. During this period, research has intensified to develop technologies to reduce or mitigate the effects of climate change. Among these technologies, Carbon Capture and Storage (CCS) technology was developed as a relevant option for the reduction of greenhouse gas emissions.

CCS technology involves capturing CO_2 from industrial sources such as steel and cement production, refineries, and power generation plants; gas compression; and transport by pipeline or ships to the final destination for either industrial use or geological storage, as noted in

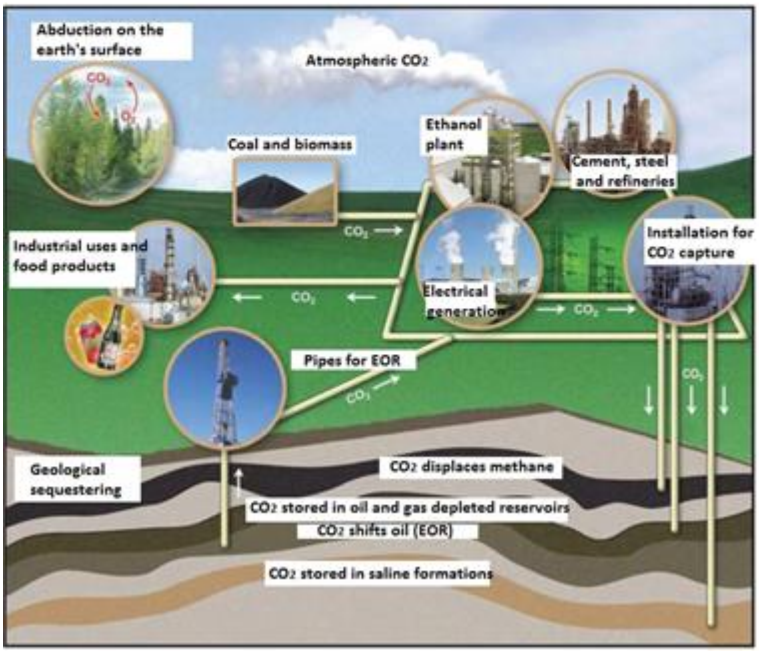

Figure 1 Scheme of carbon capture and storage technology. Source: RMCMI (2016).

It is worth highlighting from Figure 1 the main means of CO_2 utilization by the petroleum industry: displacement of methane in gas reservoirs, application as a recovery method in depleted reservoirs, and subsequent geological storage or direct storage in deep saline aquifers. The use of CO_2 as a recovery method and its subsequent use is currently referred to as Carbon Capture, Utilization, and Storage or CCUS (AMPOMAH et al., 2017). It is estimated that CCS can contribute up to 13% of the reduction in cumulative global CO_2 emissions by the year 2050 (IEA, 2015; TAN et al., 2016). Without this technology, the cost of mitigation would more than double, increasing on average by 138% (IPCC, 2014). Although CCS technology has made great progress in the last decade, accelerated development is still needed to meet international climate objectives of limiting the global average temperature increase to 2 °C by 2050 (NYKVIST, 2013; GLOBAL CCS INSTITUTE, 2015b), in addition to the objectives established at COP21 in Paris in 2016. The fact that CCS is not yet widely used is largely due to economic challenges and social acceptance, and for this reason, the implementation of successful demonstration projects is particularly important (DEAN and TUCKER, 2017).

Although CCS technology is effective in achieving large reductions in greenhouse gas emissions (GALE, 2004; IPCC, 2005; BACHU, 2008; CÂMARA et al., 2011; STIGSON et al., 2012; NYKVIST, 2013; IPCC, 2014; IEA, 2015) there is still resistance by researchers and managers in the energy sector to the development of large-scale projects. This technology is seen as a costly way to extend fossil-fuel-based power generation (BACHU, 2008; PRAETORIUS and SCHUMACHER, 2009; NYKVIST, 2013). Other authors also raise some concerns regarding the development of CCS technology that are grouped in Table 1.

Table 1. Issues of CCS development.

Issues	Authors
Countervailing efforts in other mitigation options	PRAETORIUS and SCHUMACHER, 2009; ROHLFS and MADLENER, 2013; ARNETTE, 2017
The feasibility of safely injecting large masses of CO_2 in deep formations	HOLLOWAY, 2005; LOÁICIGA, 2013; NEUMANN et al., 2013; DEAN and TUCKER, 2017; WINDÉN et al., 2013; YANG et al., 2017; ASAYAMA and ISHII, 2017
The high costs it would generate	HOLLOWAY, 2005; LOÁICIGA, 2013; MECHLERI et al., 2017; LEESON et al., 2017, DEAN and TUCKER, 2017
Burdensome conveyance logistics	PRAETORIUS and SCHUMACHER, 2009; TAN et al., 2016; LOÁICIGA, 2013; BROWNSORT, SCOTT, and HASZELDINE, 2016; MECHLERI et al., 2017; WINDÉN et al., 2013
The high volumes that need to be injected to stabilize atmospheric CO_2	HOLLOWAY, 2005; LOÁICIGA, 2013; SELOSSE and RICCI, 2017

Addressing the barriers to the development of CCS in any country involves creating a regulatory base, among other things, to help reduce the potential risks related to the implementation and development of CCS projects (PRAETORIUS and SCHUMACHER, 2009; BOWEN, 2011; DAVIES et al., 2013). Countries such as the United States of America (USA), Canada, the United Kingdom (UK), Denmark, and Australia already have laws specifically developed for CCS or that already exist in their regulatory frameworks but are applicable to most of the life cycle of a CCS project (DIXON et al., 2015). Other countries have limited or less specific regulations, which is one of the biggest obstacles to the commercial-scale performance of this technology (IEA, 2007; STIGSON et al., 2012; DAVIES et al., 2013). Brazil fits into this context (CÂMARA et al., 2011; GLOBAL CCS INSTITUTE, 2015a).

Thus, this paper proposes to compare the main regulations applied in CCS in Denmark, the UK, the USA, Canada, and Australia. The paper also analyzes the Brazilian regulations (if any) developed for this technology in order to highlight the discrepant points and the still more relevant factors that need to be developed. For this purpose, a bibliographic research using the keywords and search period described in Table 2 was conducted. In addition to these references, the analysis considered reports issued by environmental agencies, NGOs, and specific laws of the analyzed countries.

Table 2 – Evolution of papers published between 2013 and the first half of 2020. Source: Sciencedirect, Boolean search (title, abstract, keywords).

Year	"CCS projects"	"Incentives for CCS"	"Legislation about CCS"
2020	91	5	0
2019	650	166	81
2018	1326	362	145
2017	1538	379	195
2016	1137	269	157
2015	1124	281	145
2014	1418	332	167
2013	1312	313	182

The next section will give a brief review of CCS projects around the world, presenting a general overview of the regulation of CCS in the five countries studied. Subsequently, Section 3 describes the regulation in Brazil and indicates what needs to be developed for its improvement. Finally, the main conclusions of this study are presented.

2. USE OF CCS AROUND THE WORLD

By the beginning of 2017, there were 18 projects in operation around the world, generating a storage capacity of about 35 Mtpa. A total of 21 global projects are planned by the end of 2017, increasing the storage capacity to 40 Mtpa (GLOBAL CCS INSTITUTE, 2016). The International Energy Agency (IEA) suggests that by 2050 this number should increase to 6 Gton/year so that the goal of limiting the global average temperature increase to 2 °C is reached (IEA, 2015b, 2016). For this, the accelerated development of this technology is necessary. However, in-depth knowledge of CCS as a form of climate change mitigation and the lack of regulations in the most eligible countries for developing a CCS project, prevent further development of this technology. This results in a small-scale evolution in the number of projects.

In association with the slow development of projects, there is inefficiency in the granting of funds to CCS projects and a lack of adequate legislation (KAPETAKI et al., 2017; LIPPONEN et al., 2017). Private investments usually constitute the majority of the capital invested in CCS projects; few projects benefit from significant government support to offset high costs and operational risks. The USA and Canada dominate in terms of the total number of projects and levels of investment, followed by China (TOMSKI, 2015). According to the Global CCS Institute (2017), between 2008 and 2010 the US Congress approved about US $ 6.4 billion to be invested in research, development, and demonstration of CCS technology. In Australia, through the CCS Flagships program launched in 2009, the federal government earmarked A$ 1.9 billion to be invested over nine years to support two to four CCS projects on a commercial scale. However, the financing was cut over three years by A$ 459 million. Table 3 describes some examples of CCS projects cancelled or overdue and the main reasons for their cancellation or delay. It is possible to observe that the lack of specific funding and legislation has been the most common reason for the cancellation of CCS projects from the first decade of the twenty-first century (NYKVIST, 2013).

Table 3 – Cancelled or late CCS projects and reasons for cancelation. Sources: NYKVIST (2013); ZEROCO2 (2016).

Project name	Size (MW)	Main reasons for cancellation
ENEL, Porto Tolle, Italy	25% of 660 MW	Lack of positive legislation from the Italian high court
Vattenfall, Janschwalde, Germany	300 MW	Lack of legislation
Statoil, Mongstad, Norway	350 MW	Technological uncertainty
Ayrshire Power, UK	1600 MW	Local opposition and lack of legislation
Scottish Power, Longannet, UK	330 MW	Financial problems and commercial feasibility
Basin Electric, Antelope Valley, USA	120 MW	Commercial feasibility
RWE, Goldenbergwerk, Germany	450 MW	Lack of suitable storage site
ZeroGen, Australia	400 MW	Commercial feasibility
AEP, Mountaineer, USA	235 MW	Financial problems and lack of climate policies
Meri-Pori, Fortum, Finland	565 MW	Financial and technological risks and the company's updated strategy
Taylorville, USA	600 MW	Lack of legislation
Belchatow, Poland	250 MW	Financial problems
Coolimba Oxy-fuel Project, Australia	400 MW	Withdrawal of investment
Naturkraft Kårstø, Norway	420 MW	Lack of guarantee on the investments
Pioneer, Canada	450 MW	Economics

Although a number of developed countries have financing lines for CCS technology such as EEPR (European Energy Programme for Recovery) (GLOBAL CCS INSTITUTE, 2016), on analyzing Table 3 it is possible to observe that several projects have been delayed or cancelled. It is observed that financing is not an exclusive factor to guarantee the progress of a CCS project, which also requires effective regulation, consolidated technology, and environmental and market safety. Analyzing the necessity for funding in developing countries, access to the Green Climate Fund (GCF) under the United Nations Framework Convention on Climate Change (UNFCCC) could be an important opportunity for the feasibility of CCS projects. In addition, the UNFCCC Climate Technology Centre and Network can also provide an important source of policy, regulatory, and technical assistance to developing countries in improving institutional capacity and support for CCS projects (GLOBAL CCS INSTITUTE, 2015b).

3. CCS REGULATION: COUNTRY CASE STUDIES

Despite significant political and regulatory developments in recent years, the development of specific CCS regulations and laws remains a critical issue globally for both the government and project proponents. Some existing laws related to mining, oil and gas operations, pollution control, waste disposal, potable water, high-pressure gas treatment, and underground property rights may be relevant to the drafting of specific laws for the geological storage of CO_2 (IPCC, 2005). Some countries such as the UK, Denmark, Australia, the USA, and Canada have developed specific legal and regulatory systems for the long-term storage of CO_2. The main regulations of these countries applied to CO_2 storage are highlighted below.

3.1. Regulation in the European Union

The European Union has proposed a regulation for the geological storage of CO_2 presented in January 2008, called the CCS Directive, as part of an important legislative package on climate protection policy (PARLAMENTO EUROPEU & CONSELHO, 2009), and it has been in place since 2009. The Directive establishes a legal system for the environmentally safe geological storage of carbon dioxide, to be followed by the Member State or company developing a CCS project. The aspects covered by the Directive relate to the selection of the storage site, the operating and storage permits, and the operation, closure, and post-closure obligations, which correspond to the transfer of responsibility to a competent authority (PARLAMENTO EUROPEU & CONSELHO, 2009).

A fact highlighted in this Directive is that Member States should make available to the public all environmental information relating to the geological storage of CO_2 under the applicable legislation. Making this knowledge available to society is extremely important for the development of projects, as it influences the public acceptance of the application of a new technology.

Due to the high costs of geological carbon storage technology with no clear advantages, the European Union Directive has decided not to make this technology compulsory (PRAETORIUS and SCHUMACHER, 2009). In 2015, the Directive was reassessed, and no change was recommended (EUROPEAN COMMISSION, 2014).

Despite this, this Directive is a major step towards the application of CCS technology. For the broad development of this technique it is necessary i) to use clearer terminology to reduce the risks of engaging in CCS (STIGSON et al., 2012) and (ii) for Member States to put such rules into practice, beginning with transposition into the national law of the Member State, which is obligatory.

In the UK, the CCS Directive is implemented through the Energy Act 2008 (Chapter 3). To stimulate the development of CCS, the UK has implemented policy decisions, including the CCS Roadmap, from April 2012, which will support CCS's commercial development in the country by 2020; the CCS Marketing Program combined with incentives developed under the Electricity Market Reform; and the requirement that any new coal-fired power generation station demonstrate a full chain of CCS on a commercial scale for at least 300 MW of its generation capacity. These policies are enshrined as part of the six National Policy Statements, which entered into force in 2011. In addition, it also has legislation to effectively regulate CCS regarding health and safety issues added to the occupational Health and Safety at Work Act (HSWA) in 2013 (CCSA, 2016).

Denmark transferred the CCS Directive into its national law through the Subsoil Act in 2011, but with storage bans by 2020, except for CO_2-EOR (Enhanced Oil Recovery) in the offshore environment (DENMARK, 2011). This was mainly due to opposition to CCS technology from environmental organizations. The negative effect of the opposition by these organizations was not so strong in the UK, allowing the development of demonstration projects (SHOGENOVA et al., 2014).

3.2. Regulation in Australia

The Australian government has provided significant regulatory, political, and legal support for CCS, resulting in significant progress in the development and implementation of laws and regulations for this technology. A basis was the establishment in 2005, through the Ministerial Council on Mineral and Petroleum Resources (MCMPR), of the “Regulatory Guiding Principles for Carbon Dioxide Capture and Geological Storage” (DIXON et al., 2015). This document aims to facilitate a consistent national approach to CCS activities in each Australian state. For this, six key issues of a regulatory system were presented: evaluation and approvals processes, property access and legal rights; transport, monitoring, and inspections; post-closure operational responsibilities and financial aspects (CÂMARA et al., 2011).

In 2008, the Offshore Petroleum and Greenhouse Gas Storage Act 2006 (OPGGS Act) was enacted, which preserves many of the characteristics, processes, and terminologies present in the model of existing oil legislation (COMMONWEALTH OF AUSTRALIA, 2006). This act is intended to increase the certainty of operators regarding offshore sites and formations, ensuring that storage is secure. It also contains detailed provisions related to the management of interactions between CCS activities and the oil industry as well as provisions on the responsibility of the storage site and what should be done in the post-closure phase (COMMONWEALTH OF AUSTRALIA, 2006). However, issues such as risk analysis and consultation with stakeholders and the public are not specifically addressed.

Australian states must regulate onshore activities and offshore activities in coastal waters up to three nautical miles. The states of Victoria, Queensland, South Australia, and Western Australia already have legislation to regulate the geological storage of greenhouse gases or other discrete aspects of the CCS process, such as the capture, transport, or development of technologies (DIXON et al., 2015). One of the first CCS legal and regulatory regimes in the world, based on the Greenhouse Gas Geological Sequestration Act 2008 for onshore storage, was promulgated in Victoria. The offshore part is regulated by the Offshore Petroleum and Greenhouse Gas Storage Act 2010, which adopts a similar approach to the aforementioned Commonwealth Act. In addition to other issues, these acts address the injection and monitoring phases of CCS activities. In Queensland, the Greenhouse Gas Act came into effect in 2009 and is supported by the Greenhouse Gas Storage Regulations 2010. In South Australia, onshore CCS activities are regulated by the Petroleum and Geothermal Energy Act 2000. Finally, Western Australia does not yet have a state regulatory system for CCS activities, but in 2003 the Barrow Island Act 2003 was modified by the Barrow Island Amendment Act 2015 to regulate the CO_2 disposal activities applied to the Gorgon project Joint Venture (DIXON et al., 2015). Post-closure provisions and transfer of liability were not covered by the 2003 regulation but were included in the amendments made in 2015. The amendments provide for indemnities by the State to the joint venture in cases of acts or omissions made under the approval authority. The ratification by law eliminates any uncertainty about the powers of the State to enter into such agreements and can also deal with issues that require legal authority, such as the modification and acquisition of property interests and the modification of existing legislation necessary for the enterprise (BIAA, 2015).

As demonstrated by the Global CCS Institute CCS Legal and Policy Indicator (2015), Australia has developed the world's most comprehensive regulatory system to allow CCS activities. This system can be used as an example model for regulatory development related to CCS in other countries.

3.3. Regulation in USA

At the federal level, the US Environmental Protection Agency (EPA) is the agency that guides the development of policies and laws related to CCS (EPA, 2016). In the 1970s, the EPA established the Underground Injection Control (UIC) Program to prevent contamination of underground drinking water sources. The UIC Program deals with the risks of injection of various fluids, including oil field fluids, and municipal and industrial wastewater, which may result in the contamination of underground sources of

drinking water. To reform UIC, at the end of 2010, the EPA established a new class of injection well (Class VI). Class VI wells refer to those used for the underground injection of CO_2 into deep rock formations for the purpose of geological sequestration or long-term storage of CO_2 under the authority of the Safe Drinking Water Act. The program rules set forth various requirements, which include the obligations listed in Table 4. The rules apply to well owners and operators who will be used to inject CO_2 into underground storage (USA FEDERAL REGISTER, 2010).

Table 4 – Requirements for the construction of CO_2 injection wells. Source: USA FEDERAL REGISTER (2010).

Specific criteria
Extensive site characterization
Modeling of the injected area
Specification of the materials for the construction of this kind of well
Monitoring during injection operation
Monitoring during post-injection site care period
Financial responsibility for the life of the project

Another EPA program is the Greenhouse Gas Reporting Program. It was created under the authority of the Clean Air Act and is complementary to and elaborated under the UIC requirements. This program corresponds to Part 98 of the Federal Regulation number 40, coded as 40 CFR Part 98, completed by the EPA in 2010. The GHGRP sets out a rule that requires the monitoring and reporting of greenhouse gases and affects CO_2 EOR projects, acid gas injection, and carbon sequestration projects. As far as the scope of this article is concerned, this rule contains the subpart RR that concerns the geological sequestration of CO_2 (USA FEDERAL REGISTER, 2010).

Other programs developed by the EPA include (i) the ongoing construction of a regulation to clarify how CO_2 streams injected into geological sequestering will be classified under the hazardous waste requirements of the Resource Conservation and Recovery Act (RCRA); and ii) the Vulnerability

Evaluation Framework, which provides policy makers, stakeholders, industry, and the public with a transparent framework for assessing the vulnerability associated with geological sequestration sites (EPA, 2016). Other US agencies, including the Interagency Task Force Interagency on CCS, Department of Energy (DOE), and the Department of the American Geological Survey, are developing strategies to accelerate the development and commercial deployment of CCS, involving research and development programs, whether privately, with partners in industry, universities, and non-governmental organizations, or governmentally (EPA, 2016).

The Safe Water Drinking Act provides states with the option of assuming primary responsibility for the implementation of the UIC program when certain requirements for the primacy of the state, such as ensuring that state regulations are equally rigorous and effective, are fulfilled. Issues addressed by state regulations include, among others, porous space ownership, eminent domain for CO_2 transport pipelines, and long-term responsibility for stored CO_2 (BONHAM and CHRYSOSTOMIDIS, 2012). The federal legislation for CCS, developed under the UIC program and the Safe Drinking Water Act, which aims to protect shallow drinking water sources, results in a robust legal and regulatory foundation when grouped into broader and established health, safety, security, and environmental frameworks. Despite this federal focus and the various state-level legal and regulatory developments that have attempted to address the remaining gaps, CCS is not treated comprehensively and integrated fully at either federal or state level in the USA (DAVIES et al., 2013; GLOBAL CCS INSTITUTE, 2015a).

3.4. Regulation in Canada

Provincial governments in Canada led the way in developing legislation to support the deployment of CCS technology. However, they have different positioning in relation to CO_2 storage, which to a certain extent reflects the primary energy mix, the greenhouse gas emission profile, and the CO_2 storage potential. From the regulatory point of view, the implementation of CO_2 storage is the responsibility of the energy sector regulatory agencies. However, the protection of groundwater is the responsibility of the national environmental agencies, which consider the potential for leakage and also assess the impact on the environment (IEA, 2007).

The provinces of Alberta, British Columbia, and Saskatchewan have well developed regulations for the production of hydrocarbons and can be used to treat CO_2 storage associated with Enhanced Hydrocarbon Recovery (EHR) (IEA, 2007). In 2010, the Alberta government enacted the Carbon Capture and Storage Statutes Amendment Act, which replaces various provincial energy statutes to provide clarification regarding the regulation of CCS activities in the province (LEGISLATIVE ASSEMBLY OF ALBERTA, 2010). To complement this Act, this province also approved the Carbon Sequestration Tenure Regulation in 2011, which establishes the processes that companies must follow to obtain rights to possession or rent of the porous space. These rights allow companies to assess the suitability of a potential site for CO_2 storage (ALBERTA ENERGY, 2016). Amendments have also been made to the Mines and Minerals Act, which makes it clear that porous space is owned by the Crown, and new provisions have been included that allow the transfer of post-closure responsibility for stored CO_2 to the province. These amendments also establish a post-closure management fund to cover the costs associated with transferring responsibility to government (LEGISLATIVE ASSEMBLY OF ALBERTA, 2010). Although the legislation developed in Canada is not as extensive as that in Victoria, Australia, or as determined by the CCS Directive in the European Union, it has important characteristics in relation to pore space ownership and the management of long-term storage liability.

3.5 Regulation synthesis of CCS in the case studies

The most and least developed main contents in the legislation of each country were evaluated by the comparative analysis carried out by the Global CCS Institute (2015a) according to the five criteria described in Table 5.

Table 6 summarizes the legislation developed for CO_2 storage activities in the five aforementioned countries.

Table 5 – Assessment criteria in the comparative analysis of the Global CCS Institute. Source: Global CCS Institute (2015a).

Assessment Criteria	Description
1	Clarity and efficiency of the administrative process of applying for and obtaining regulatory approval for CCS projects
2	Comprehensiveness of the legal framework in providing for all aspects of a CCS project, including siting, design, capture, transport, storage, closure and monitoring for potential releases of stored CO2
3	The extent to which the CCS legal and regulatory framework provides for the appropriate siting of projects and adequate environmental impact assessment processes
4	The extent to which the CCS legal and regulatory framework provides for and incorporates meaningful and effective stakeholder and public consultation
5	The way in which laws and regulations deal with long-term liability for closure, monitoring, and accidental releases of CO2

Table 6 – Comparison of CCS legislation among Australia, Canada, Denmark, the USA, and the UK.

Country	Base of legislation	Main laws	Main content	
			Most developed criterion	Least developed criterion
Australia	Mining and Oil and Gas Industry	1. Offshore Petroleum and Greenhouse Gas Storage Act 2006 – Federal 2. Greenhouse Gas Geological Sequestration Act 2008 – Victoria, Onshore 3. Offshore Petroleum and Greenhouse Gas Storage Act 2010 – Victoria, Offshore 4. Greenhouse Gas Act 2009 – Queensland 5. Petroleum and Geothermal Energy Act 2000 – South Australia, Onshore 6. Barrow Island Act 2003 – Western Australia	1	4
Canada	Energy	Carbon Capture and Storage Statutes Amendment Act, 2010 – Alberta	1	4
Denmark	Environment	Subsoil Act 2011	5	1; 2
USA	Environment	1. Safe Drinking Water Act (UIC class IV), 2010 2. Greenhouse Gas Reporting Program 2010	3	2; 4
UK	Environment	Energy Act 2008	1; 5	4

From the analysis in Table 5, it can be seen that criterion 1 is the most developed criterion in existing legislation in Australia, Canada, Denmark, the USA, and the UK for the regulation of CCS technology. This criterion refers to the clarity and efficiency of the administrative process for requesting and obtaining regulatory approval for CCS projects. Additionally, criterion 5 has also been developed significantly in CCS regulations in the countries concerned. This criterion deals with the long-term liability, which includes closure, monitoring, and accidental releases of stored CO2. The fact that these two criteria are the most developed in the existing regulations is probably due to the fact that they are one of the main pillars for the creation of the projects, permission, and management.

On the other hand, it is possible to identify that criterion 4, concerning legislation which envisages and incorporates public consultations and stakeholders that are significant and effective, is the least developed criterion in existing legislation. This is because this criterion, along with criterion 3 on environmental impacts, is considered of secondary importance in relation to the others for the development of CCS projects (GLOBAL CCS INSTITUTE, 2015a). In Europe, the Member States, according to the Directive, should make available to the public all environmental information relating to the geological storage of CO_2 under the applicable legislation. However, in Denmark the strength of the environmental organizations against CCS conducted to storage bans by 2020, which may be a reason for lack of development of regulations related to public consultations. In Australia, USA and Canada, the different positioning of the governments in the states and provinces in relation to CO2 and its storage, may be a reason for the criterion 4 being the least developed in these countries when their legislations are analyzed. It is worth noting that public acceptance of CCS technology as an option to mitigate climate change influences the viability of this technology. Such acceptance is strongly based on public confidence in stakeholders, mainly due to a lack of knowledge about technology (TERWEL et al., 2011).

The analysis of existing legislation in these countries makes it possible to highlight some points that still need to be developed in the various phases of the life cycle of a project.

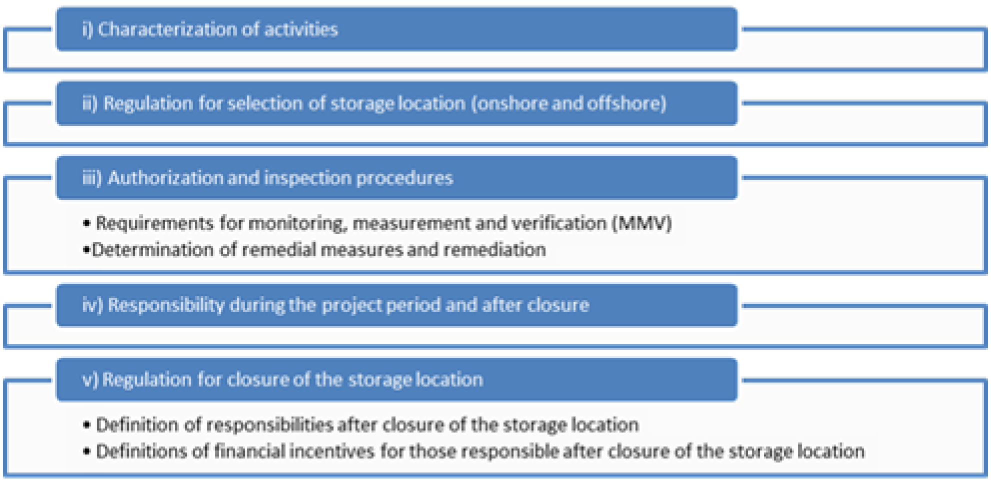

Figure 2 – Points to improve existing legislation.

The lack of criterion 4 in the legislations aforementioned (as in Australia, USA and Denmark), together with the points exposed in Figure 2; the strength of opinions from environmental organizations against CCS (as in EUROPE, mainly in Denmark); and the comprehensible way that the CCS legislation is written and integrated at either federal or state level (criterion 2, as in USA and Denmark), may be some of the reasons that even in countries with well stablished legislations there are projects that have been cancelled, as observed in Table 3.

4. REGULATION IN BRAZIL

During the UNFCCC in 2010, Brazil undertook to take appropriate mitigation actions to reduce its emission intensity through Decree 7.390/2010 (BRASIL, 2010). This decree regulates the National Policy on Climate Change institutionalized in Law 12,187 / 2009, which aims to reduce between 36.1 and 38.9% its projected emissions until 2020 (BRASIL, 2010). It is worth noting that these emission reduction values are based on data from the Brazilian Energy Research Company (Empresa de Pesquisa Energética, EPE), which indicated in 2010 that fossil fuels would be responsible for the projected 234-MtCO_{2eq} increase in emissions by 2020 in the absence of mitigating actions.

The Center for Excellence in Research and Innovation on Petroleum, Mineral Resources and Carbon Storage (CEPAC) was inaugurated in 2007 and has been working closely with government agencies such as the Ministry of Science and Technology and industry stakeholders such as Petrobras. One of the objectives of this center is the implementation of pilot and demonstration projects for CO_2 storage and energy production. In July 2014, the center published the first Brazilian Atlas of Geological Capture and Storage of CO_2 (CEPAC, 2016).

Based on the regulations of the countries analyzed in this paper and following the model of the regulatory framework for CCS proposed by the IEA (2010), it was possible to analyze the regulatory process of CCS in Brazil. Unlike the countries analyzed, there are no specific Brazilian laws dealing with the storage of CO_2. The development of a regulatory system for CCS, whether at state level or federal level, also depends on the country's interest in policies and the development and implementation of climate mitigation technologies. In the case of CCS, countries and states that do not have options or capacity to store CO_2 or where sources of energy supply are not based on fossil fuels will not show as much interest in the implementation of policies that enable the development of CCS. The fact that Brazil is committed to the development of renewable energy sources may be one of the reasons for the delay in the development of the regulation applied to CCS, as it is the first issue for CCS development listed in Table 1.

Brazil keeps an opposite attitude related to the inclusion of CCS technology as a Clean Development Mechanism (CDM). One reason for this position is that Brazil believes that CDM projects should be used to promote cleaner and renewable technologies and not to promote the use of fossil fuels (CÂMARA et al., 2011); however, the last SEEG (Greenhouse Gases Emission Evaluation System, 2018) report reveals that CO_2, individually, represents 73% of the total emissions in 2016. One of its mains sources was the burn of fossil fuels. Hence, the developing of CCS technology and legislation is reasonable; in view of Brazil is a developing country and its emissions lean to increase.

In the Brazilian legislation there are only laws relating to the environmental policy and to the oil and mining areas. These, in turn, can be applied in some part of the CO_2 storage process. However, in order to subsidize the specificities related to CCS technology, it is important, firstly, to classify CO_2 as industrial waste, mineral resource, or commodity (as in the USA in EHR operations) and secondly, to determine the composition of the CO_2 stream to be injected. These aspects will influence the legislation to be elaborated. Some legal basis for regulation can be harnessed from existing legal norms, such as international laws for the protection of the marine environment, since Brazil is a signatory of the London Convention; property rights; issues of human health protection; and the environmental impact assessment. However, important issues, such as the characteristics of storage and the appropriate location for this, are important aspects to regularize the construction of CCS projects, which are not yet regulated in the country.

The development of CCS laws and policies in Brazil can be governed by agencies related to mining and oil, such as the National Petroleum Agency (ANP) and the National Department of Mineral Production (DNPM), due to the technological similarities of the activities carried out and some regulatory requirements. Through the ANP it might be possible to keep track of the monthly information related to CCS activities, including EOR or storage in mature and depleted hydrocarbons fields. It is also possible to obtain information on the regularization of the production and sale of CO_2 for commercialization in national or international territory. Besides the ANP, the National Water Resources Council (CNRH) can also be mentioned. It can contribute to the specific regulation related to the conservation of groundwater and issues of regularization of the reuse of non-potable water. This regulation can be refined to consider deep saline aquifers, which are potential storage sites for carbon dioxide. Another important institution for the possible regulation of CCS in Brazil is the National Environment Council (CONAMA). It can take advantage of the legislation regarding the environmental impacts caused by a possible leak of CO_2 as well as issues related to the licensing of CCS activities. One can also mention the National Agency of Terrestrial Transports (ANTT), which regulates the terrestrial transportation of dangerous products, which could include CO_2. Schematically,

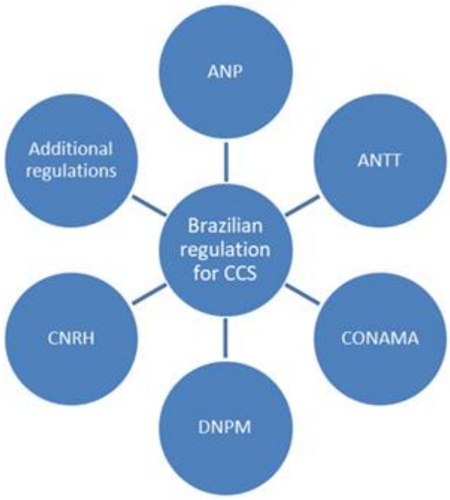

Figure 3 – Possible agencies to set up the base of CCS legislation in Brazil.

This analysis evidences that specific regulations will be required for CCS, considering that the existing laws do not specifically apply to the topic. A good example to be followed by Brazil is regulation in the European Union, which through the Carbon Capture and Storage Directive has regulated the geological storage of CO_2 without the technology becoming mandatory until it reaches a commercial scale. It is also noted that the clarity and efficiency of the administrative process of applying for and obtaining regulatory approval for CCS projects and the clear definition of responsibilities are important factors in the development of technology. In this way, the Brazilian regulations must clearly define the parties involved and their responsibilities, similarly to what happens in the regulation of the Brazilian petroleum industry.

5. CONCLUSIONS

Most countries seem to prefer to make amendments to existing regulations to create specific CCS laws. Thus, for the regulatory development of CCS in Brazil, can initially be based on existing laws in the oil and mining industry and the necessary amendments can be made to adapt these laws to CO_2 storage activities. A good example to be followed is regulation in the European Union, which through the Carbon Capture and Storage Directive has regulated the geological storage of CO_2 without the technology becoming mandatory.

In order for the developed regulation to positively influence the implementation of CCS projects, clarity is needed in the implementation of the rules, so that the terminologies do not contribute to the increased risk of engaging in this technology. The Australian regulatory system was considered the world's most comprehensible. This system can be used as an example model for regulatory development related to CCS in Brazil as well, in order to avoid lack of clarity.

The countries' regulations highlighted in this work were accessed in a limited period of time and with specific keywords. It was possible to observe that several other countries, mainly Asian countries, have recently presented works related to the development of regulation. It is suggested that future studies assess the regulatory model being proposed in these countries.

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