Analysis of Civil Liability Regarding CCS: The Brazilian Case

Article · June 2017

DOI: 10.15341/mese(2333-2581)/06.03.2017/003

Modern Environmental Science and Engineering (ISSN 2333-2581)
June 2017, Volume 3, No. 6, pp. 382-395
Doi: 10.15341/mese(2333-2581)/06.03.2017/003
Academic Star Publishing Company, 2017
www.academicstar.us

Analysis of Civil Liability Regarding CCS: The Brazilian Case

José Ricardo Lemes de Almeida[1], Haline de Vasconcellos Rocha[2], HirdanKatarina de Medeiros Costa[2],Edmilson Moutinho dos Santos[2], Cristina F. Rodrigues[3], and Manoel J. Lemos deSousa[3]

1. University Fernando Pessoa, Portugal

2. Institute of Energy and Environment, University of São Paulo, Brazil

3. Fernando Pessoa Energy, Environment and Health Research Unity, University Fernando Pessoa, Portugal

Abstract: Global energy demand is still increasing based on consumption of fossil fuels, and its consequences such as greenhouse gases emissions (for instance CO_2 emissions) are concerns for humanity due to the global warming. In the context, climate changes issues are clearly one of the big issues for our future. Thus, measures for mitigating its effects are treated, discussed, and analyzed to help us to reduce those problems. In this regards, Carbon Capture and Storage (CCS) technology may represent a strategic alternative for CO_2 abatement. Using bibliographic review methodology; including law analysis as well as the development of a logical explanation approach and deductive reasoning, in this paper, we analyzed the climate change mitigation strategy of CCS, and the perspectives of implementing this technology in Brazil, as well as we discussed the Civil Liability regarding CCS, focusing on the Brazilian environmental law. Our results show that the lack of a legal and regulatory framework of CCS activities represents the main barrier to its national development.

Key words: carbon capture and storage (CCS), civil liability, regulation, Brazil

1. Introduction

The beginning of the 21st century is characterized by new challenges in the energy sector and energy planning, which result, mainly, from an increasing energy demand. These challenges correlate to three main problems. First, the reduction of conventional hydrocarbon reserves, that is, oil and associated natural gas, where, in the case of oil, it is estimated a 50% reduction in the initial amount of reserves [1]. Second, the problem of increasing external energy dependence, in other words, lack of energy security. Finally, the need to promote a more sustainable and effective global energy development [2]

Global energy demand was boosted by the global population growth, which has practically doubled in the last 45 years — from 3.713 billion in 1970 to 7.496 billion in 2016 (UNRIC, 2016) — and by the quality of life improvement. This energy demand increased from approximately 6,000 Mtpe (mega tons of equivalent oil), in the early 1970s, to over 13,000 Mtpe in 2015, which corresponds to an increase of 123%. According to projections, global energy consumption will increase by 48% between 2012 and 2040 [3]. Fig. 1 illustrates the evolution of primary energy consumption in the world [3, 4].

In order to respond to this demand's growth, the political and social scenario that permeates the energy sector is capable of mobilizing efforts so renewable energy sources becomes sufficiently competitive, through an economic perspective. However, until this competitive parity is reached, the search for a

Corresponding author: José Ricardo Lemes de Almeida, MSc., research areas/interests: energy, coal, CCUS. E-mail: almeidaj@colband.com.br.

sustainable energy plan will still be based on the usage of fossil fuels for energy generation. In fact, it is expected that fossil fuels remain the world's leading source of energy for the next two to three decades [2, 5].

Despite the global concern regarding global warming, the consumption of fossil fuels will continue to be the global inducer of economic growth. Therefore, carbon dioxide (CO_2) abatement strategies gained highlight in the agenda of the various international energy stakeholders, due carbon's relevant contributing factor to the greenhouse effect. CO_2 is currently the main pollutant emitted from the combustion of fossil fuels (anthropogenic emissions). Fig. 2 shows the evolution of these emissions in the last 140 years, whose growth is associated with the increase in the demand for fossil fuels, reaching almost 32 Gt of CO_2 in 2012 [3].

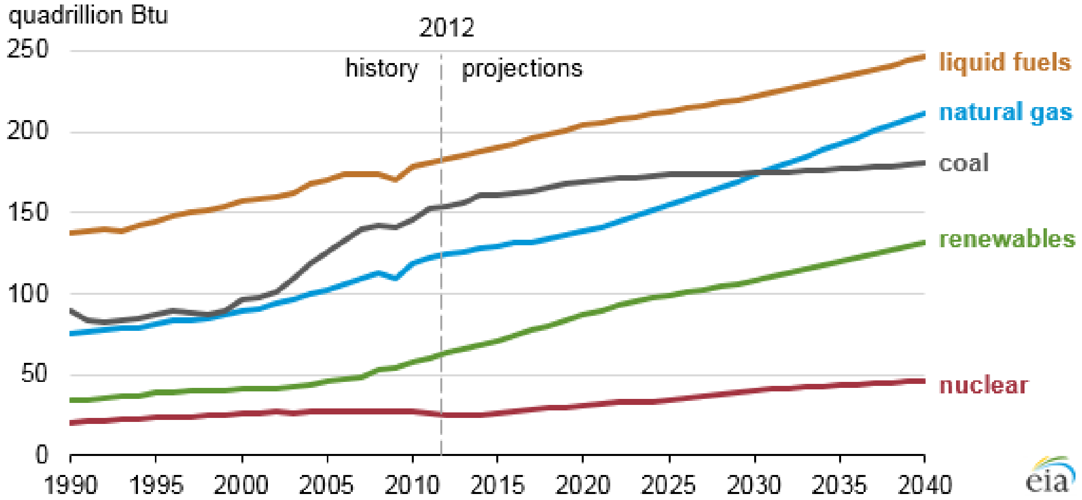

Fig. 1 Primary energy consumption worldwide, by source, from 1990 to 2040 [3].

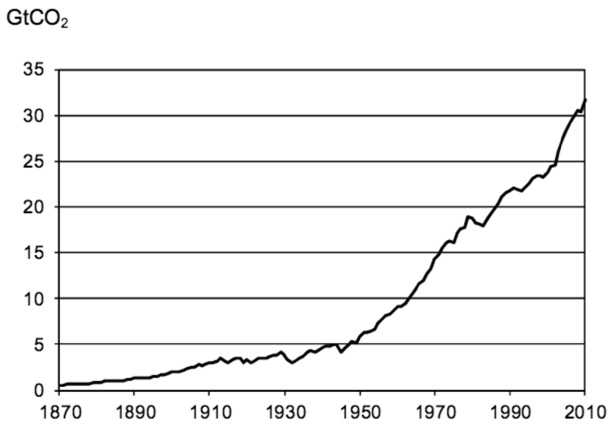

Fig. 2 Evolution of CO_2 emissions, from burning fossil fuels [3].

According to what is shown in Fig. 2, from the upward trend of the curve, CO_2 emissions were intensified in recent years. In 2002, it was estimated that from 1751 to 2002, 1070, 106 tons of CO_2 were produced. At the time, projections for the period of 2003 to 2039 were of 735,106 tons of CO_2, that is, 69% of the real quantity produced between 1751 and 2002, but in 14% of the time (36 years against 251 years) [6]. Given the scenario of energy concerns, in 2015, Brazil submitted its Nationally Determined Contribution (NDC)[1] proposal to the Paris Agreement (COP 21), ratified in 2016. With NDC Brazil, aligned with the Sustainable Development Objectives (ODS), more specifically to ODS 7[2] and ODS 13[3], the country undertook the aim to reduce greenhouse gas (GHG) emissions by 37% by 2025, with reference to 2005

[1] NDC Brazil: "Decline per capita emissions in Brazil in order to reach approximately 6.2 tCO2e in 2025 and 5.4 tCO2e in.

[2] ODS 7: Accessible and Clean Energy. Goal 7.a: "by 2030, strengthen international cooperation to facilitate access to clean energy research and technologies, including renewable energy, energy efficiency and cleaner fossil fuel technologies, as well as to promote investment in energy infrastructure and in clean energy technologies."

[3] ODS 13: Fight Climate Change. Goal 13.2: "Integrate climate change mitigation approach into national policies, strategies and planning."

emissions. This target is quantified in emissions of 6.2 tCO2e (trillion of equivalent carbon dioxide) per capita until the proposed date (2025) (UNIC Rio, 2015).

Currently, power generation is one of the main carbon emitting sources in Brazil, accounting for 43.6% of CO_2 emitted from stationary sources (Fig. 3). This sector produces more than 170,000 kilotons (kt) of carbon dioxide per year [7].

In order to mitigate carbon emissions, the creation of public policies and regulatory frameworks are essential for minimizing negative externalities in the context of climate change [8]. In this context, considered as one of the main alternatives for CO_2 emissions reduction, the Carbon Capture and Storage (CCS) technique gained prominence by its permanent storage capacity of high volumes of $CO_{2,}$ in appropriate geological formations. This technique consists on the injection of compressed CO_2 (in the supercritical state) into rocks such as sandstones, shales, dolomites, basalts or coal. In order to become CO_2 reservoirs, besides retaining adequate porosity and permeability, these rocks must present a satisfactory seal and a stable geological environment in order to avoid compromising the integrity of the storage site. In addition, monitoring is essential to ensure that CO_2 remains permanently stored within these geological formations [9].

Concerning the Brazilian scenario, CCS technology may represent a strategic alternative for CO_2 abatement, especially to the energy sector. However, the knowledge regarding this technology is still little consolidated among the country, as well as the respective regulation of this activity [8].

In the absence of a specific regulation for CCS, the principles of civil liability are mechanisms that can be used to compensate those who suffer damages from this activity, as well as the considerations from the Brazilian environmental legislation. CCS projects have risks, especially regarding CO_2 leakage, becoming necessary to discuss who will repair the damages when accidents occur, and who will be responsible for repairing damages to people and the environment.

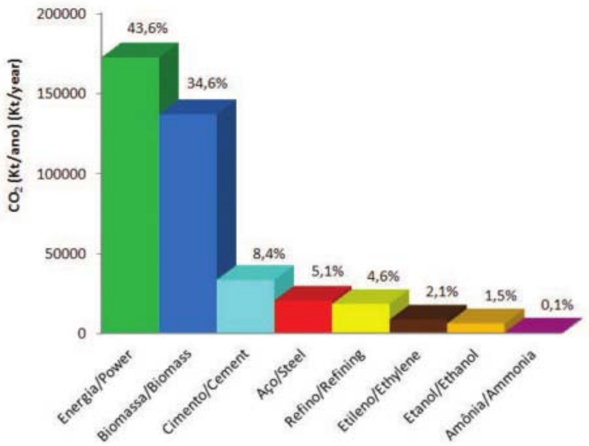

Fig. 3 CO_2 emissions in Brazil per industry.

Through this perspective, this article presents an preliminarily analysis regarding the civil liability concept, as well as its possibility to serve as an instrument for understanding possible damages and associated issues that may occur from CCS activities. For the development if this research, our methods were based on bibliographic review; including the analysis of environmental law, as well as the development of an approach of logical explanation and deductive reasoning. We analyzed the carbon capture and storage (CCS) as a climate change mitigation strategy, the perspectives for implementing this technology in Brazil, and its correlation to civil liability, focusing on environmental legislation.

We will first present the Civil Liability concept, as well as its history and development in Brazil. As the following, the CCS technology will be presented and detailed, considering the associated risks to this activity and the alternatives for risks abatement. Furthermore, a discussion about Civil Liability regarding CCS will be presented. And, finally, we will conclude with the main considerations and recommendations for a creation of a legal and/or regulatory framework for CSS in Brazil.

2. Civil Liability Context and Its Presence in Brazilian Civil Code of 2002

Since the 18th century, civil liability has emerged as a matter of great importance in legal discussions, affecting people's daily lives. Not that it was left to

forgetfulness throughout the history of law, even because this is not confirmed by the development of discipline, but by the fact that the history of humanity goes back to the idea of responsibility. As already said by Aguiar Dias "the march of civil responsibility represents the very evolution of law" [10]. Thus, what is presented is the vigorous insurgency of the idea of reparation for injustices committed within society.

In this point, the Mazeud brothers had already observed the absorbing tendency of civil liability, becoming the center of legal activities [10]. Some authors bring the question about social motivation that made such assertion possible. Is it solidarity, the yearning for social justice, awareness of individual, collective and diffuse rights, or just selfishness and survival of the human being? [10].

Well, the widening of civil liability is clear, in all fields of law is widespread to provide for redress in case of damage, from the subjective liability, which is the rule, to strict liability, when expressed.

According to Pereira (2001, p. 13), "the law is unanimous and unanimous in doctrine when it states in general terms the principle of responsibility, proclaiming without contradiction and without blunders, that the victim of an offense against his rights and interests shall receive compensation from the offender."

Thus, following this trend based on doctrine and jurisprudence, the Civil Code of 2002, Law No. 10406/02, reserved a title within the general part, Title III, of unlawful acts, arts. 186 to 188, to the subject, as well as in Title IX dealing with Civil Liability, arts. 927-954. However, in a sparse manner, this Civil Code disciplined certain particular aspects (articles 12, 20, 43, 206, § 3, articles V, 398, 406, 1298, 1,296, 1,311, sole paragraph, 1,385, §3, among others).

In the following item, we bring the main modifications presented in the Civil Code regarding the discipline of strict civil liability, its concept, and its historical overview with its evolution.

2.1 General Knowledge, Concept and Historical Evolution

The origin of the term responsibility comes from the Latin verb "respondere", which means that someone is a guarantor of something. In the *solemestipulatioromano* the expression *sponde* created an obligation for who pronounced it, regardless of cause *debendi* [10].

For many Brazilian jurists, the one who managed to better understood the concept of civil liability in within the country was Serpa Lopes [10]. In this term, "liability means the obligation to repair a damage, due to guilt or other legal circumstance that justifies it, such as presumed guilt or a purely objective circumstance" [10]. The fundamental correlation between damage and reparation is perceived, and Serpa Lopes was fortunate to mention the objective or independent responsibility by fault [10].

It is necessary to emphasize the difficulty, pointed out by the jurists, of statically and objectively delimiting the lines of the civil liability concept, according to Facchini (2002, p. 154) [11], "there is hardly in civil law a larger, more confusing and more difficult systematization matter than civil liability." According to Facchini (2002, p. 155) [11], "the new civil law did not substantially alter this state of affairs. There were few deep and significant innovations. Most of the apparent legislative changes are nothing more than an incorporation into the law of consolidated or trend-setting jurisprudential understandings."

With due respect, one can see the technical prominence of the legislator by bringing to the Civil Code exactly the most established current jurisprudence and doctrine regarding liability. It is believed that the Code has revolutionized the civil liability, incorporating consolidated trends, and following closely the provisions of the Federal Constitution of 1988. The law must follow the evolution of society, and in the positivist system like ours, finding a device in law is not to raise doubts, is to raise the principle of legal certainty.

Historically, the phases of civil liability, in general terms, are the first one based on the private revenge (*vindita* phase) in which tribes met and fought, not seeking guilt, aiming only at vengeance, representing a stage of collective responsibility. Pass through that, the *taliao phase*, in which the penalty is according to the act. Finally reaching the phase of *composition*, and hence the notion of reparation, in which public authority ensures the punishment of the guilty.

Well, in historical terms it is worth noting that "Roman law did not arrive at a theory of civil liability ... it was all built up in the development of cases of species, decisions of judges and praetors (...). Not for this, however, is it to disregard the historical evolution of civil responsibility in Roman law" [12].

However, in 286 a. C. (probable date according to Mario Cute Jordãoapud Pereira, 2001), Lex Aquilia lays the bases of the liability, but continues the punitive character, merely objective. "It is attributed to the origin of the guilty element, as fundamental in the reparation of the damage. (...) its greatest value is to replace the fixed fines with a penalty proportional to the damage caused" [12]. Subsequently the French Civil Code of 1804 (Napoleonic Code), predicting responsibility with guilt, being really peaceful point in doctrine as the first modern code foresees such figure, in its art. 1.382: *Tout fait quelconque de l'homme, qui cause à autrui um dommage, obligueceluipar la fauteduquelilestarrie, à lêreparer*.

Since the Industrial Revolution, the growing usage of machinery and the consequent exacerbation of damage to employees led to the need of revising the civil liability rule, based only in guilt. Therefore, it was developed theoretical formulations of the strict sense civil liability. From this point on, the civil liability doctrine [4] have made progress in order to create explanations related to the risk-benefit, the risk creating and the full risk theories. The first is liability only because it has a positive aspect, and in case of damage it should be repaired, "it was fair that those who collected the benefit, the advantages of a company, should indemnify those who, without being able to expect the same benefits to be victims of accidents" [11].

The theory of risk creating corresponds to the sole paragraph of art. 927 of the New Civil Code, that is, it is the risk of the activity itself, the harmful potentiality of this activity. On the other hand, the theory of full risk means the there is non-examination of any aspect of extra damage, that is, the damage occurred, it was identified the perpetrator, who is subject to repair, regardless of causation [13]. For instance, under the Brazilian environmental law, the civil liability for ecological damages is based on the theory of full risk and strict tort liability.

These species should be seen as methods of applying strict liability, ensuring that the victims are sure to be repaired from the damage that they were suffered. "Where subjective (or traditional) theory cannot explain and base the right to compensation, one must rely on strict theory. This is because, in a truly fair society, all unfair harm must be repaired" [11].

This item closes with the idea that Brazilian Civil Law has progressed in establishing the general rule of strict civil liability, assuring the repair to injured and in addition to punishing the responsible, and providing the harmony so desired by the society regarding of activities with potential risks.. In this line, in the following topics, we talk about CCS technology and its correlation with strict responsibility.

3. Carbon Capture and Storage (CCS)

Carbon Capture and Storage technology is seen as an important medium-term option to mitigate the effects of global warming. CCS projects seek to reduce the concentration of greenhouse gases by capturing CO_2 directly from emission sources. The carbon dioxide is then stored by an injection processes into underground geological formation, such as active and abandoned oil and gas reservoirs, saline aquifers, or coal shafts [14].

[4] The exclusions of responsibility are a fortuitous case, force majeure and exclusive fault of the victim.

The CCS technique comprises a set of technologies that act according to the following processes:

(1) Carbon capture: from of gaseous effluents. Consists on the separation of CO_2 from other gases, compression for volume reduction and fluid accommodation. Occurs at specific points of generation, such as thermoelectric plants or cement manufacturing industries. Different methods can be applied, especially absorption, adsorption, membrane separation and cryogenic separation;

(2) Carbon transport: compressed by pipelines, by ship or by truck, from the production unit to the storage location;

Carbon storage: CO_2 storage types can be grouped, as shown in Fig. 4 and Fig. 5, into two categories: biological fixation (biotic sequestration) and geological storage (abiotic sequestration). Fig. 4 also indicates the main locations that are designated for storage.

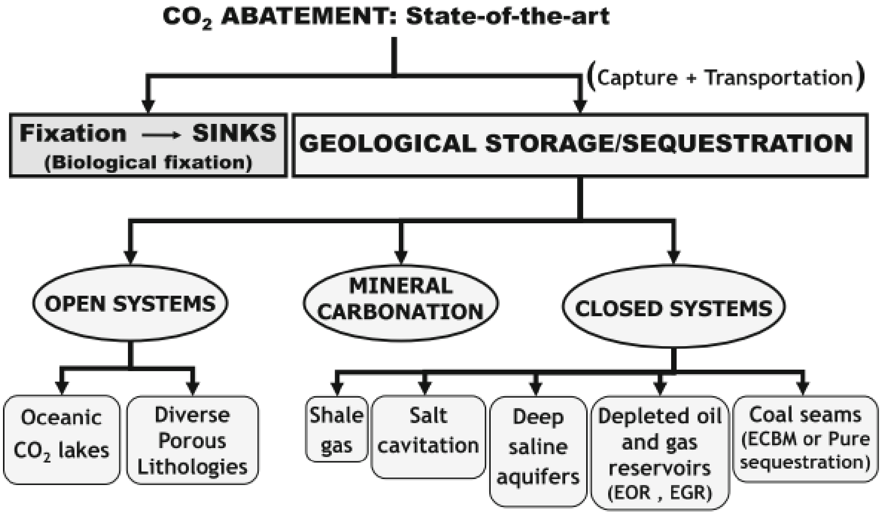

Fig. 4 CO_2 abatement: state of art [2].

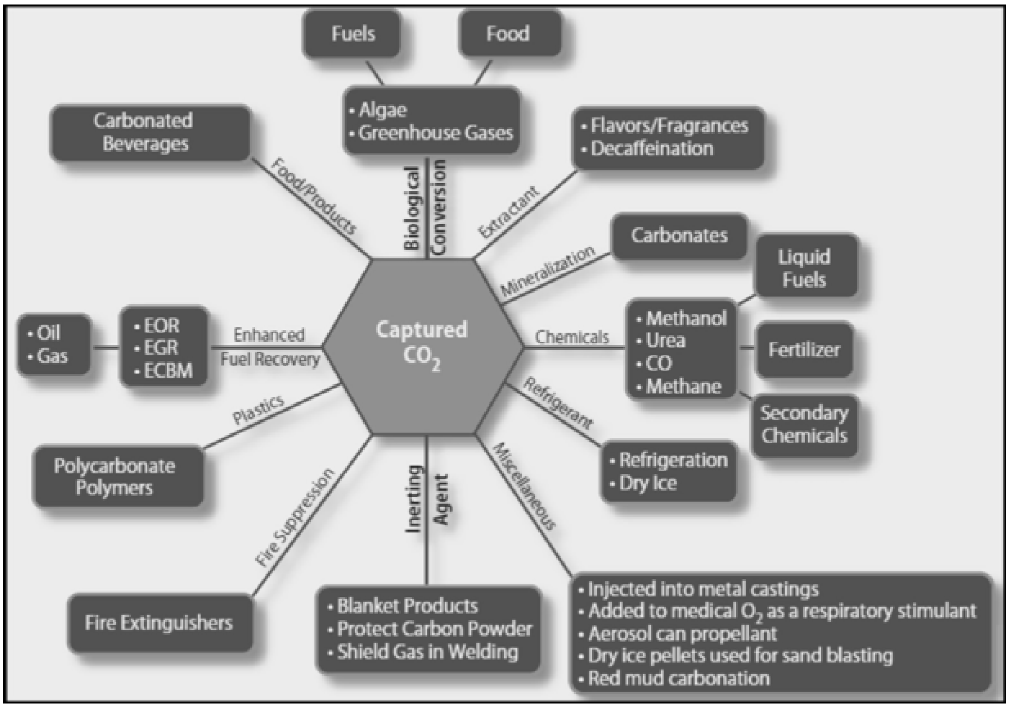

Fig. 5 Diagram representing the varied and plentiful current and potential usages of CO_2 [2].

As regards the geological sequestration, several studies have shown that biological fixation is technologically possible but can be economically unfeasible — due to different constraints such as the associated flue gas produced from the industry, which has high CO_2 concentration levels and toxic chemical compounds (SO_x and NO_x). Nevertheless, several geological solutions have been considered technologically and economically feasible for CO_2 storage, such as: (1) depleted oil and gas reservoirs, (2) deep saline aquifers, (3) coal seams, (4) shale gas, and (5) mineral carbonation (storage in mineral form in ultrabasic rocks) [2].

Once potential storage locations have been identified, based on previous geological described criteria, the feasibility of applying this technology depends on the incorporation of economic and environmental aspects. Locations that are very distant from CO_2 emission sources, or which are associated with a high level of technical uncertainty, become unfeasible for carbon storage. In general, the selection of storage locations must consider, in addition to the intrinsic criteria already mentioned, extrinsic conditions, such as the following [15]:

(1) Proximity between transmitting sources and storage locations,

(2) Adequate level of infrastructure for CO_2 capture and transport,

(3) Existing wells, for injection and monitoring of possible leaks,

(4) Production and/or injection strategies,

(5) Right of exploitation on the ground/subsoil,

(6) Proximities of population occupations, and

(7) Cost and economic viability.

According to Ketzer et al. (2015) [7], Brazil has an overall favorable situation regarding the potential for CO_2 geological storage; which includes large areas covered by sedimentary basins (both onshore and offshore), and the synergies with the location of stationary emitting sources — especially in the south and southeastern regions, major emitting sources are located in proximity to these basins. Major emitting sources are represented by power plant, biomass, cement, steel, oil refining, ethanol, ethylene and ammonia sectors [7, 8].

Since 2014, these have being three pilot projects and one large-scale integrated CCS project in Brazil. In the Brazilian Pre-Salt, Lula CCS Project is the first large-scale integrated project (LSIP) installed in Brazil. The exploitation of the Lula Pre Salt Field (originally named as Tupi) was initiated in 2010, and the CCS project stated operation in large scale since 2013. The main motivation to deploy CO_2 geological storage in the Pre-Salt zone relates to the great content of CO_2 identified in some wells (in the case of the Lula field, an estimate of 15% of CO_2. The project operates with direct injection of CO_2 into the geological formation; therefore, no additional pipelines are required for transport [8]. Although the CCS technology is already well known by the petroleum sector, and well recognized by Petrobras, the lack of a regulatory framework is holding back the development and implantation of this technology in Brazil.

3.1 Associated Risks

As mentioned, carbon dioxide storage in geological media is a climate change mitigation technology that is based on the ability of certain geological media to retain $CO_{2,}$ in supercritical phase [5] or dissolved in formation water, and to prevent its return to the atmosphere for very long periods of time. However, in certain cases there are flow pathways, natural or manmade, conducive to CO_2 leakage. The effectiveness of geological carbon storage depends on the combination of physical factors, or trapping. In general terms, carbon storage is safe and effective, however, some projects implemented have shown CO_2 leakage, caused by improper sealing, drilling holes and/or abandoned wells, and by geological instability and consequent faults and fractures. Depending on

[5] CO_2 in the supercritical state: physical state in which there is no distinction between the liquid and gaseous phases.

their condition, existing oil and gas wells may provide such leakage pathways due to either mechanical defects, developed during well drilling, completion and/or abandonment, or to chemical degradation of well cements and/or casing [16].

As previously described, the risk of injecting CO_2 into geological formations depends on the amount of fluid and gas present in the rock, its permeability and the volume of gas to be injected. Due to these factors, the injection can be successful or exceeded, and thus leak and infiltrate into aquifers, rivers and atmosphere, and, in addition, create a pressure accumulation in the storage tank, fracturing the surface [17]. The environmental impacts of CO_2 geological storage can be integrated into two types: local environmental effects and global effects, on the atmosphere. Global effects can be seen as uncertainty in the efficiency of CO_2 storage. Local risks are represented by possible CO_2 leakage, which may result from (1) high concentrations of CO_2 in the gas phase near the surface, (2) dissolution of CO_2 into groundwater (aquifers) and (3) effects induced by displacement of fluids with the injection of CO_2 (seismic activity) [18]. Risk types of carbon leakage are represented in Fig. 6.

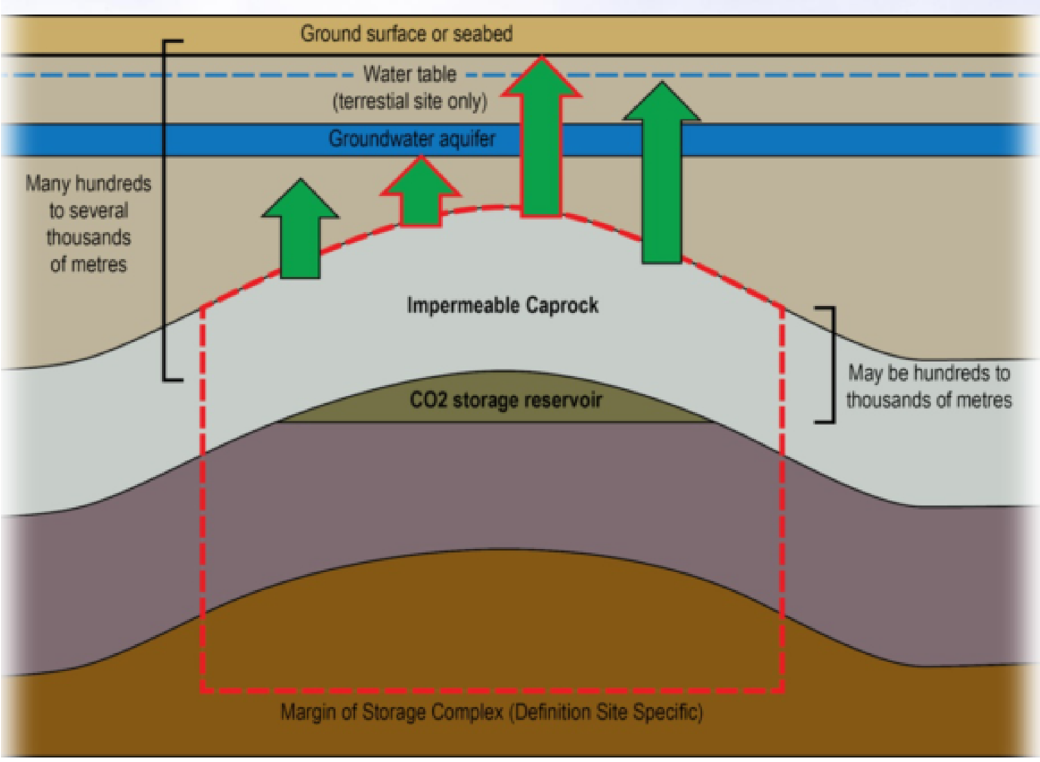

Fig. 6 Schematic illustration of a CO_2 geological storage system (outlined in red) and the risks of possible leakage (green arrows) according to EC Storage Directive [21, 28].

According to Leal e Sousa (2015) [18], the main risks of CO_2 geological storage vary according to the storage location and are mainly: (i) the configuration of the storage facility, including the geological characteristics of the selected stratum; (ii) the heterogeneity of the seal; (iii) geological heterogeneity (stratigraphic heterogeneity, existence of discontinuities, etc.); (iv) knowledge of the existence of nearby pumping and/or injection wells; (v) the suitability of the injection system; (vi) alteration of biogeochemistry; (vii) geomechanical weathering (generation of faults and fractures); (viii) methods of abandoning wells when the reservoir reaches the limit.

Previous studies suggest that one of the first requirements to be met in selecting an appropriate storage location was the presence of several layers of sealing — or cap rock. Therefore, in a closed system, it is possible to make early detection of potential risks. If

CO_2 leakage occurs, the monitoring system will trigger the technician. If the problem is not resolved, the secondary sealing layers will act on the leakage retention. According to the Leal e Sousa (2015) [18] & Lemos de Sousa (2009) [1], large scale commercial CO_2 storage projects should be adopted if it is assumed that the site is well chosen, designed, operated and monitored. Available data from existing projects suggest that the fraction of CO_2 stored trapped in the first 100 years is more than 99% and it is possible that the fraction of CO_2 stored trapped in the first 1000 years is greater than 99% [6, 18].

3.2 Risk Abatement

In order to prevent leakage and to remain CO_2 stored for millions of years, the storage conditions must be ensured via subsurface monitoring. These safety activities include means of geophysical monitoring, such as seismic and electrical resistivity, and geochemical monitoring, by means of fluid analysis. The CO_2 injection phase must be monitored at all stages, from its planning to completion, and it is important to study and predict the injected gas and fluids from rock formation's behavior, as well as the interaction among those. Strict characterization is required to select appropriate storage locations with adequate capacity, injectivity and stored volume [7, 19, 20].

Through a social and environmental perspective, reliable and cost-effective monitoring will be an important part of making CCS a safe, effective, and acceptable method for CO_2 control. Monitoring should be required as part of the permitting process for underground injection, and can be used for a number of purposes, such as (i) tracking the location of the plume of injected CO_2, (ii) ensuring that injection and abandoned wells are not leaking, and (iii) verifying the quantity of CO_2 that has been injected underground. Additionally, depending on site-specific considerations, monitoring may be required to (iv) ensure that natural resources, such as groundwater and ecosystems, are protected and that the local population is not exposed to unsafe concentrations of CO_2 [16].

In addition to monitoring activities, a detailed risk assessment process ir required in order to ensure low probability of leakage, and that any associated impact can be appropriately identified, monitored and mitigated. According to the literature, the leakage of 1% of CO_2 stored/per 100 years is the amount acceptable [7].

Evidence indicates that CO_2 leakage is not likely to occur if site selection, characterization and storage project design are undertaken correctly. As a safety guarantee, in Europe was created the Storage Directive [20], which provides a legislative framework, implemented by Member States, which requires appropriate project design to ensure the storage of CO_2 is permanent and safe. Based on studies undertaken by EC, entitled RISCS project, the following conclusions were draw [21, 22]:

(i) Impacts from CO_2 leakage are expected to be small compared to impacts caused by other stressors. These additional stressors include, but are not limited to, changes in land use, extreme onshore weather events, periods of abnormal weather and activities such as bottom trawler fishing, as well as the impacts that CCS seeks to mitigate such as climate change and ocean acidification.

(ii) It is recommended that storage operators, and relevant Competent Authorities, demonstrate that an appropriate level of understanding has been developed of the potential impacts that might arise if a leak did occur from the specific site being considered for CO_2 storage.

(iii) Evaluation of risks of leakage and potential impacts should be undertaken at each site, since each will have specific characteristics which will influence the nature and scale of the environmental response. The context of what specific impacts mean for a particular storage site

(e.g. selection of crops) is fundamental and should be explained where relevant.

(iv) The research undertaken in RISCS, and reviewed research published elsewhere, indicates that there are no reasons why a storage project could not be sited within any of the large-scale environmental types that have been studied here.

(v) Potential impacts will be further reduced by careful site selection and appropriate monitoring and mitigation plans.

(vi) All monitoring programs should use ecosystem evaluation techniques. Monitoring technologies and assessment methodologies have been developed and tested that allow the impacts of CO_2 in terrestrial and marine environments to be assessed.

(vii) Indicator species that occur within specific onshore sites have been identified that can be monitored in conjunction with other environmental factors to assess the scale of an impact and the efficacy of any remediation.

Based on the exposed information, we can observe that the risks regarding CCS activities, especially associated with carbon leakage, go beyond generations, ongoing to hundreds to thousands of years. Those risks are more associated with the geological time scale than with the human time scale. In order to facilitate safe and economic carbon storage, risks abatement strategies require a regulatory framework that addresses the unresolved issues regarding the regulation of a large, industrial-scale CCS program. As already said, it is is necessary a discussion about CCS regulatory issues, including mandatory monitoring requirements and risk assessments. Regarding the Brazilian context, characterized by the lack of a legal and/or regulatory framework for CCS, this discussion includes the Civil Liability concept, and it is brought to this article. In this line, the following section brings an overview and its limitations may be studied for interested researches in this field.

4. Civil Liability Regarding CCS

In Brazil, with regard to CCS activities, it is necessary to increase regulatory capacity and build support for government authorities in order to develop a deeper understanding of how this technology and liabilities should be applied [8, 23]. It is important to consider that CCS projects goes beyond centuries and that can become a liability for the State if the operating company terminates the CCS activity. As already said, the single paragraph of Article 927 of the Brazilian Civil Code (2002) states the risk-creating theory that corresponds to it concerns the activity itself, the damaging potential of this activity, as it says: "There will be the obligation of repairing the damage, regardless of guilt, in cases specified by law, or when the activity, often performed by the author of the damage, implies, by its nature, risk for the rights of others." However, Brazilian environmental law applies the full risk theory, which means the non-perquisition of any extra damage aspect, i.e., if there was damage, if the author of it is identified; he/she is responsible for the recovering, regardless of the causality. Therefore, these species must be seen as strict sense liability application methods to assure to victims the reparation of suffered damages.

According to Romeiro-Conturbia (2014) [8], and based on international experience, a legal and regulatory framework for CCS activities in Brazil should incorporate the following aspects: (i) the indication of the competent regulatory authority; (ii) the definition of property rights and CO_2 ownership at the subsurface; (iii) the designation of environmental licensing requirements; and (iv) the allocation of liability.

For this study, we are focusing on the storage of CO_2. Hence, regarding the competent regulatory authority, and according to Romeiro-Conturbia (2014) [8], a representative from the National Agency of Petroleum, Natural Gas and Biofuels (ANP) would be responsible to regulate CO_2 storage in oil fields, a representative from the National Agency of Mining would be

responsible to regulate CO_2 storage in coal mines and other continental geological formations (i.e., shale gas), and a representative from the National Water Agency (ANA) would be responsible to regulate CO_2 storage in saline aquifers.

Based on of property rights and CO_2 ownership at the Brazilian subsurface, and in the context of the public international law, the States retain sovereignty over subsoil resources, and may regulate their exploitation solely based on national laws. Hence, Article 20 of the current Brazilian Federal Constitution [24] establishes that all mineral resources (including those of the subsoil) are owned by the federal government (the Union).

Regarding designation of environmental licensing requirements, environmental law in Brazil is broad enough to encompass the activities involved in the various CCS project activities. The environmental licensing is the main regulatory tool, and it is regulated by the National Environmental Policy Act (Federal Law no 6.938 of 1981) and involves the participation of civil society in the decision-making (through public hearings). In addition, the National Environmental Council (CONAMA) established the Resolution n^o 01 of 1986 to request an environmental impact assessment (EIA) and environmental impact report (EIR) before the competent environmental regulatory agency concedes an environmental licensing for an activity or enterprise. The EIA-EIR is a tool to assess the impact of an activity or enterprise and to provide the corresponding measures to mitigate such impacts. For the storage of CO_2, the resolution has category on "extraction and mineral treatment" with a sub topic on well drillings and oil and gas production. Based on this, it can be assumed that either the drilling of new wells or the modification of oil wells to store CO_2 would be subject of approval by the competent environmental regulatory agency (IBAMA) [8].

In regards to allocation of liability, as already said, Brazilian Civil Code does not have a specific mention to the liability related to CCS activities; however, we may apply Law 6938/81 that prescribes the theory of full risk and strict tort liability.

Although, according to Beck et al. (2011) [19], CCS provides 20% of the total reductions in CO_2 emissions by 2050 and therefore will require an ambitious growth path for this technology globally, risks of potential carbon leakage need to be considered and prevented by law, as well as ensuring the permanence and safety of CO_2 storage [25].

In the case of carbon capture and storage activities, a parallel comparison to the Federal Constitutions rules on civil liability for nuclear damages may imply that the operators of a CCS project would be the liable entities to respond for any damage related to the leakage of stored CO_2, even in those accidents caused by armed conflict, hostilities, civil war etc [8].

It is worth highlighting that countless sparse legal diplomas have already described the strict liability, such as Law n. 6453/1977, which discusses the civil liability for nuclear damages as well as the criminal liability for acts related to nuclear activities. Thus, Bittar (1985) [26] classifies the activity as dangerous due to its condition and to the employed means (substances, devices, machines and dangerous instruments), which bring danger. Finally, they might have in them a remarkable damaging potential regarding the mid-normality criterion.

5. Conclusions and Recommendations

According to the conducted study, large-scale deployment of CCS is still subjected to diverse political, economic, environmental, and social challenges. In this scenario, it is necessary to increase regulatory capacity and build support to governmental authorities in order to develop a further understanding on how this technology and liabilities should be applied [8, 27]. In this context, the single paragraph of Article 927 of the Brazilian Civil Code (2002) states the risk-creating theory that corresponds to it concerns the activity itself, the damaging potential of this activity, as it says: "There will be the obligation of repairing the damage,

regardless of guilt, in cases specified by law, or when the activity, often performed by the author of the damage, implies, by its nature, risk for the rights of others." However, Brazilian environmental law applies the full risk theory, which means the non-perquisition of any extra damage aspect, i.e., if there was damage, if the author of it is identified; he/she is responsible for the recovering, regardless of the causality. Therefore, these rules must be seen as strict sense liability application methods to assure to victims the reparation of suffered damages.

Reducing costs, designing legal and regulatory frameworks as well as enhancing public acceptance have been some of the key issues in the deployment of large-scale carbon capture and storage (CCS) projects worldwide. According to the International Energy Agency (IEA, 2016), "legal and regulatory frameworks are critical to ensuring that geological storage of CO_2 is both safe and effective and that storage sites and the accompanying risks are appropriately managed after sites are closed". The long-term liability for potential leakage of stored carbon dioxide or any other potential damage has been considered as one of the most multifaceted subjects related to CCS regulation [8, 19].

Based on the international experience, the combination of this with enhanced oil or natural gas recovery, as a combined "zero emission" cycle, can provide financial feasibility to its development and increase demand. In addition, the majority of CCS projects worldwide are in petroleum reservoirs, which makes more favorable to CCS in Brazil to develop within the petroleum (oil/gas) industry: the exiting projects are being conducted offshore, and operated by Petrobras, which reinforces the possibility that the CCS technology develops in association with the petroleum sector. In this perspective, and in accordance to Romeiro-Conturbia (2014) [8], the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) can be indicated as the competent regulatory authority in order to regulate CCS projects in Brazil, in the energy and petroleum sectors. The author also emphasizes that "a multidisciplinary approach with a diversity of possible competent regulatory authorities would be the most appropriate option to regulate different CCS projects in Brazil." In general terms, although the only large-scale CCS project as of 2014 in Brazil is related to the oil and gas industry, it is important to bear in mind that in the mid and long-term there could be other viable options to deploy CCS in the country.

The idea that the Brazilian law has progressed through the establishment of the general rule of strict tort liability for the risk-activity theory was accepted, it has as main aim assuring reparation to the victims, punishing those responsible for the damage, and promoting the so desired social harmony through the regulation of such activities. With regards to the environmental scope, the Article 14, first paragraph of Law 6938/1981 already described the objective for environmental damage: "§ 1 — without hampering the application of the penalties described in this article, the polluter, regardless of the existence of guilt, is obligated to compensate or repair the damage caused to the environment and to third parties affected by its activity. The Federal and State Public Prosecutors will be legitimate to suggest criminal and civil responsibility action for damages caused to the environment." Brazilian Civil Code does not have a specific mention to the liability related to CCS activities; however, we may apply Law 6938/81 that prescribes the theory of full risk and strict tort liability in order to prevent potential CO_2 leakages from geological storage. Moving towards CCS development.

It is recommended to focus on activities that accelerate confidence in carbon storage and its security, including clarification and development of regulatory frameworks to minimize the associated uncertainties. In this scenario, more efforts are needed to ensure that CCS and carbon mitigation are well understood among policymakers in Brazil, training not only for the industry but also for the government, in order to create

an ideal environment for national development and for CCS development. A specific CCS regulatory framework in Brazil is likely to include a range of existing regulations that will require joint coordination among the many ministries and stakeholders.

Acknowledgements

We acknowledge the support of the RCGI Research Centre for Gas Innovation, sponsored by FAPESP (2014/50279-4) and Shell, , and the strategic importance of the support given by ANP (Brazil's National Oil, Natural Gas and Biofuels Agency) through the R&D levy regulation and the Human Resources Program PRH n.04. In addition, we acknowledge the support of CAPES and Colégio Bandeirantes.

References

[1] M. J. Lemos De Sousa, Sem energia fóssil, o apagão, in: Medina C. & Medina S. (Eds.), *Energia, Meio Ambiente e Comunicação Social*, Porto/São Paulo: Novo Pacto da Ciência, 2009, pp. 57-74.

[2] C. F. A. Rodrigues, M. A. P. Dinis and M. J. Lemos De Sousa, Review of European energy policies regarding the recent carbon capture, utilization and storage technologies scenario and the role of coal seams, *Environmental Earth Sciences* 74 (2015) (3) 2553-2561.

[3] International Energy Agency (IEA), *World Energy Outlook 2016*, 2016.

[4] Centro De Informação Das Nações Unidas Para O Brasil (UNIC RIO), Agenda 2030, available online at: https://nacoesunidas.org/pos2015/agenda2030/.

[5] G. M. T. D. S. Oliveira et al., Tecnologias CAC e Inquéritos de Percepção da Opinião Pública sobre "O papel da Captação e do Armazenamento/Sequestração de Dióxido de Carbono no Futuro da Energia na Europa": O caso-de-estudo da Comunidade Fernando Pessoa, CCS Technologies and Inquiries into Public Perception on "The Role of Carbon Dioxide Capture and Storage in Europe's Energy Future": The case-study of University Fernando Pessoa Community, 2009.

[6] M. J. Lemos De Sousa et al., CCS Technologies in Europe (Carbon Capture and Storage)/As Tecnologias CAC na Europa (Captação e Armazenamento de Carbono). Sessão Académica: Classe de Ciências, As Tecnologias CAC (Captação e Armazenamento de Carbono) na Europa, Lisboa, 4 de Julho de 2013, 13-15 horas, 2013.

[7] J. M. Ketzer et al., Brazilian Atlas of CO_2 capture and geological storage, *EDIPUCRS* (2015) 66.

[8] V. R. D. S. Romeiro-Conturbia, *Carbon Capture and Storage Legal and Regulatory Framework in Developing Countries: Proposals for Brazil*, 2014.

[9] S. Ansolabehre et al., *The Future of Coal – An Interdisciplinary MIT Stu*dy, 2007.

[10] França Edílson. Responsabilidade Civil. Notas de Sala de Aula: UFRN, 2002.

[11] FACCHINI NETO, Eugênio. Da responsabilidade civil no novo Código, accessed 09 Mar. 2017, available online at: http://aplicacao.tst.jus.br/dspace/bitstream/handle/1939/13478/001_facchinineto.pdf?sequence=2.

[12] Pereira Caio Mário da Silva, *Responsabilidade Civil* (9th ed.), Rio de Janeiro: Forense, 2001.

[13] H. K. M. Costa, Santos M. M. and P. Matai, Capitulo 17 - Questões ambientais e Licenciamento ambiental, No prelo, 2017.

[14] V. Lima, Armazenamento geológico em CO_2 em aquíferos salinos: reatividade química em selos e rochas reservatório da Bacia do Paraná, Pontifícia Universidade Católica do Rio Grande do Sul, 2010.

[15] S. Bachu, Carbon dioxide storage capacity in uneconomic coal beds in Alberta, Canada: Methodology, potential and site identification, *International Journal of Greenhouse Gas Contro* 1(2007) (3) 374-385.

[16] National Energy Technology Laboratory, DOE/NETL Carbon Dioxide Capture and Storage RD&D Roadmap, December, 2010, p. 67.

[17] S. T. Anderson, Risk, liability, and economic issues with long-term CO_2 storage — A review, *Natural Resources Research* (2016) 1-24,

[18] R. Leal E. Sousa, Risk assessment on CO_2 injection processes and storage, in: *Conference on Underground Clean Energy and CCUS*, 2015.

[19] B. Beck et al., The current status of CCS development in Brazil, *Energy Procedia* 4 (2011) 6148-6151.

[20] EC, *Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide — Guidance Document 1: CO_2 Storage Life Cycle Risk Management Framework*, 2009, p. 54.

[21] J. Lions et al., Potential impacts of leakage from CO_2 geological storage on geochemical processes controlling fresh groundwater quality: A review, *International Journal of Greenhouse Gas Control* 22 (2014) 165-175.

[22] R. Patil, Impacts of carbon dioxide gas leaks from geological storage sites on soil ecology and above-ground vegetation, *Diversity of Ecosystems* (2012) (2) 27-50.

[23] International Energy Agency, Tracking clean energy progress 2013, *Technology*, 2012, pp. 1-82.

[24] BRASIL, Presidência da República do (2016). Lei da PNMA, accessed on 09 March 2017, available online at: https://www.planalto.gov.br/ccivil_03/Leis/L6938.htm.

[25] The European Academies Science Advisory Council (EASAC), Carbon capture and storage in Europe, EASAC Policy Report 20, 2013.

[26] Bittar Carlos Alberto. *Responsabilidade civil nas atividades nucleares*, São Paulo: RT, 1985.

[27] IEAGHG. Review of CO_2 storage in low permeability strata: Potential implications on gas production from shales and coals for geological storage of CO_2, 2013.

[28] European Commission, Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006, *Offical Journal of the European Union* L140/114 (2009) 114-135.