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THE BRAZILIAN CARBON CAPTURE AND STORAGE (CCS) INSTITUTIONAL FRAMEWORK: THE NEW CARBON MARKET BUSINESS IN AN ENERGY TRANSITION ECONOMY

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Thesis submitted to the Energy Postgraduate Program, Institute of Energy and Environment (IEE) of the University of São Paulo (USP), for the degree of Doctor of Science.

Ph.D. Supervisor: Profa. Dra. Hirdan Katarina de Medeiros Costa

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Aos amigos que, por motivo alheio, foram levados pela tragédia do COVID-19

Aos familiares de antes, irmão, irmã, afilhado e mãe,
Aos familiares recentes, minha companheira e minha filha,
pois, sem vossos suportes, amor e apoio, meus caminhos não seriam esses!

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Que nunca foi sorte, sempre foi Exu!

(Emicida)

RESUMO

ARAUJO, Israel Lacerda de. **Arcabouço institucional brasileiro para captura e armazenamento de carbono (CCS): o novo mercado de carbono em economia de transição energética**. Tese (Doutorado), Programa de Pós-Graduação em Energia, Instituto de Energia e Ambiente. Universidade de São Paulo, 2021.

Esta tese propõe modelo institucional para o desenvolvimento das atividades de captura e armazenamento de dióxido de carbono (CCS) em estrutura geológica sob arcabouço legal e regulatório. Como premissa, o trabalho defende viés com a meta de melhor aproveitamento dos potenciais brasileiros em mercados de carbono com base na tecnologia de CCS, sob ótica de melhor resultado no longo prazo, de indução e incentivo por meio de instrumentos fiscais, regulatórios e de políticas públicas. Ademais, o objeto se insere em ambiente de transição energética para uma economia de baixo carbono, com argumentos delineados a reduzir os custos para os consumidores, os custos relacionados à incerteza política, de responsabilidade de longo prazo, e de falhas de mercado que inercialmente tendem à propensão de comportamentos de captura de renda, de oligopólios inter e intrasetoriais, e que, em sentido amplo, tendem a verticalização e a redução do engajamento de outros segmentos que não a indústria do petróleo e de bioenergia. Por meio de estudo comparativo, foram abordadas boas práticas de implementação de política de CCS, destacadamente aquelas adotadas nos EUA, no Canadá, na Noruega, no Reino Unido, nos Países Baixos, nos Emirados Árabes e Arábia Saudita. Neles, a pesquisa comparativa obteve resultados consistentes na presença de instrumentos com finalidade de absorver falhas de mercado vinculadas às mudanças climática e aos mercados, e especificidades políticas. No Brasil, foram avaliados os incentivos vigentes para setores adjacentes ao CCS, em que se concluiu haver condições para formação de clusters setoriais envolvendo a produção de biocombustíveis, energia elétrica, e especialmente hidrocarbonetos sob CO_2-EOR. Ainda, nos resultados, verificou-se que a avaliação da percepção institucional demonstra indícios de que o modelo legal, regulatório, normativo e institucional deve se lastrear no empoderamento de poucas autoridades regulatórias e políticas (RCA e PCA, respectivamente), com base nas instituições vigentes, de forma incremental, mantendo o engajamento dos atuais setores com elevada emissão de CO_2-GHG segundo *business as usual*. Além disso, deve se ponderar questões relacionadas à transferência de custos aos consumidores finais sob o risco de comprometer questões de percepção pública e de veto político. Conclui-se que o modelo a ser implementado no arcabouço jurídico brasileiro precisará apresentar soluções para virtualmente reduzir riscos de longo prazo, político e entre cadeias ou setores, horizontalmente e verticalmente.

PALAVRAS-CHAVE: CCS, análise institucional, mudanças climáticas, incentivos econômicos, economia de baixo carbono, transição energética

ABSTRACT

ARAUJO, Israel Lacerda de. **The Brazilian Carbon Capture and Storage (CCS) institutional framework: the new carbon market business in an energy transition economy**. Thesis (Doctor of Science), Energy Postgraduate Program, Institute of Energy and Environment. University of São Paulo, 2021.

This thesis proposes an institutional model for the development of Carbon Capture and Storage (CCS) under the legal and regulatory frameworks in Brazil. This model allows agents using best practices and take advantages of the Brazilian potential in the carbon markets, national and international, based on the CCS technology and under the long-term perspectives. Through a comparative study, the CCS best practices and the implementing policies have been analysed, especially those in the USA, Canada, Norway, the United Kingdom, the Netherlands, the UAE, Saudi Arabia and China. For them, the instruments pursued tried to solve market failures linked to climate change and political specificities, and to incentivize the CCS deployment. The study analysed also how to incentivize the CCS technology through fiscal, regulatory and public policy instruments, considering the premise of reduced impact of costs for consumers (and citizens), the need of dealing with political uncertainties, the long-term responsibilities, and the market failures that inertially work in favour of rent seeking behaviour, inter- and intra-sectorial oligopolies in which, in a broad sense, would tend to verticalize business and reduce the engagement of other than the oil industry and bioenergy agents. In Brazil, the current incentives for the CCS adjacent sectors indicate a potential deployment to the CCS clusters using the production of biofuels, electricity, and particularly for hydrocarbon exploitation under the CO_2-EOR. The institutional perception allows us to conclude that the legal, regulatory, normative and framework for the CCS business should be built considering the empowerment of a few regulatory and political authorities (RCA and PCA, respectively), the existing institutions, promoting changes incrementally to maintain the current engagement of prior sectors with high CO_2-GHG emissions according to business as usual. In addition, issues related to the complexity of costs' transfer to final consumers should be considered, under the risk of compromising public perception and political veto. The model to be implemented in the Brazilian legal framework will need to present solutions to virtually reduce political and long-term risks, cross-chains risks horizontally and vertically.

KEYWORDS: CCS technology, institutional assessment, climate change, economic incentives, low carbon economy, energy transition, regulatory framework

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1. GENERAL INTRODUCTION

This Ph.D. research brings available an innovative approach to the Carbon, Capture and Storage (CCS) framework, suggesting a state-of-the-art Brazilian institutional framework for tackling bottlenecks of the new CCS business in the new green deal and the low carbon economy of the current century, embracing major emitting sectors and its Greenhouse Gas (GHG) large-scale facilities. It aims to provide academic subsidies for decision-makers in assessing vital political barriers for implementing the CCS legal system, the incentives to deal with market failures, and potential synergies between Brazil and other climate-committed countries. Therefore, the institutional assessment of the CCS business in Brazil.

The research has been developed under a research group dedicated to building a legal framework to proposed regulatory, normative, and institutional solutions for Brazil's potential carbon dioxide sequestration.

1.1. GENERAL BACKGROUND

The scientist's consensus pointed to the unprecedented increase of the total amount of carbon dioxide in the atmosphere in such a short timeframe by human activities, mainly fossil fuel uses, as the cause of the global temperature risen (IPCC, 2014).

These concerns surpass the academic circles and achieve political agenda, being the most relevant the 21st Conference of the Parties (COP-21) to the United Nations Framework Convention on Climate Change (UNFCCC) - The Paris Agreement, in 2015. The member states compromised to contribute relevantly in order to keep the global average temperature below 2 °C and to pursue efforts to limit its increase to 1.5°C above the pre-industrial, which represented a milestone in the multilateral climate agreements, for studying and analysing the countries' behaviour and, consequently, for the institution's redesign and how agents act through its rules to reducing carbon dioxide emission levels.

Therefore, the current climate change emergency has required effective actions to promote Greenhouse Gas Removal (GGR).

To achieve that, the key stakeholders in its countries have spent energies developing institutional frameworks and elect technologies that reduce current CO_2-GHG levels by changing production chains, consumer habits and then achieving global scale' low carbon economy and pattern. The international organisms have proposed procedures to assist countries in the climate mitigation policies, for instance, the necessity of tackling GHG hard-to-abate industries challenges.

1.2. STATEMENT OF THE PROBLEM AND RESEARCH PURPOSE

The key instruments to achieve net-zero emissions have been the energy efficiency, the renewable energy – wind, solar, hydro, and biomass thermopower plant – and nuclear sources, and the electrification. However, these three key guides may not tackle properly the for the GHG in the hard-to-abate sectors in terms of costs, scale and feasibility. For them, the present technologies make the Carbon Capture (Utilization) and Storage (CCS or CCUS) a feasible solution regarding the dependence of current infrastructure and the path of decarbonizing industries (European Environment Agency, 2011; IEA, 2011a, 2019).

Nevertheless, the crucial challenge to be faced concerning the CCS activity is the complexity between the high-level political decision and the path from conceptual implementation and the actual policy in the diversity of production chain, suppliers involved, consumers, intersectoral gains and losses, and respectively impacts in the regional alliances, subnational entities and the long-term commitment with climate change.

The absence of a comprehensive legal framework for the CCS, defining liabilities, distributions of risk among its chain, and the studies of potential agents' behaviour represents a bottleneck for deploying CCS large-scale projects. These factors increase risks' perception and result in long-term problems of monetizing GGR in the low carbon economy.

Brazil could achieve its NDC target without implementing the new CCS technology. However, the country could lose the opportunity to implement it and then participate effectively in the new business of Bioenergy with CCS (BECCS) once it figures as a critical share of the negative emissions after the second half of the century, providing benefits globally to tackle the climate emergency.

For that, this research proposes to assess and diagnose the CCS activities in Brazil based on comparative studies focused on normative and legal frameworks, on institutional assessment of stakeholders' perception of the CCS activity.

In addition, it proposes to investigate the institutional framework' and its mechanisms for making viable the CCS business, comparing international experiences and the convergences with public policies of adjacent sectors, the competent authorities in the Brazilian institutional system that may act in the regulatory and normative process focusing on prospective models, the convergences of the CCS framework in the hard-to-abate sectors, and the incentives that may shape agents' behaviour, and potential mechanisms to reduce transaction costs and market failures in the climate change agenda.

In sum, the main objective is to analyse the institutional frameworks for the CCS business in Brazil considering:

i. The debate of GHG emission through the geological time and the recent influence of humans in the environment;

ii. The cost-benefit assessment and the transactional costs to mitigate market failures in the CCS related chains;

iii. The convergence among international experience and the current Brazilian institutions associated with CCS

iv. The competent authority framework design that may reduce long-term costs and deploy quickly large-scale projects in Brazil

v. The current incentives and policies for CCS opportunities in selected sectors; and

vi. Institutional perception from stakeholders about the CCS business in Brazil.

1.3. THESIS STRUCTURE

This thesis comprises a total of nine chapters, including the present introductory chapter and conclusions and considerations. The research results in a collection of seven coherently articulated chapters, each intentionally written for ongoing or later submission in specialized journals.

The first three chapters review how the institutional assessment theories may help to understand CCS activities.

Chapter 2 discusses a historical view of climate change diagnosis and how the CCS technology may mitigate climate change challenges. Our methodology is a literature review of technical and economic questions of CCS and the analysis based on geological data.

Chapter 3 comprehends the Original Institutionalism, New Institutional Economics, and the Institutional Analysis and Development framework, combining them to relevant CCS topics to investigate the implementation process of large-scale projects under the GGR situation and understand the CCS activities bottlenecks over time.

Chapter 4 analyse the costs and benefits of the CO_2-GHG chain related to CCS technology, the economic benefits of the diffused losses, and the natural arbitration role for the government. The methodology used was the critical analysis of producer-consumers economic behaviours, production chains, and the main rules involved. We found that CO_2-GHG emitting agents tend to get stuck on the market failures of infrastructure-regulated or commodities-related industries.

After review, the following chapters are the broad institutional assessment of the CCS activity (chapter 5) and the thesis results (chapters 6 to 8).

Chapter 5 aims to analyse international experience in deploying the CCS large-scale projects to investigate how they adapt their legal systems, regulatory framework, and long-term uncertainties that prejudice to follow up the CCS-GGR projects. It is found that innovative schemes may solve key issues pointed to the literature. It is highlighted that singular liability arrangements or public funds have been shaped to transfer the ownership of carbon dioxide injected, exonerating the main unsolved future risk. In addition, a combination of favourable tax exemption, fiscal incentives, and the carbon market allows a good long-term incentive for CCS projects.

Chapter 6 examines the theme of Brazil's carbon capture and storage activities' institutional competencies. The methodology is an analytical and qualitative assessment of current institutional frameworks and theoretical reference and perceptions matrix. In addition to the supervisors, Mrs. Yane Marcelle Silva participated in this part of the research.

Chapter 7 examines the current Brazilian incentives under the energy legal frameworks and promises innovative changes to deploy CCS large-scale projects. The methodology proposed to analyse whether the CCS large-scale projects in Brazil could be implemented using current incentives for adjacent activities related to critical sectors or punctual enhancements in their institutions, based on significant economies expertise and the lock-in conditions of the energy sector. The partial result was previously presented at the conference. As co-author, Mr. Danilo Perecin and Mrs. Isabela Morbach, being available as Proceedings of the 15th Greenhouse Gas Control Technologies Conference 15-18 March 2021.

Chapter 8 aims to investigate the institutional framework and stakeholder's perception from the energy sector, governmental members, and researchers to better understand the decision paths to the prospective CCS large-scale activities in Brazil as an emerging economy.

The Middle-Out Perspective (MOP) has been identifying internal and external influences, the organizational analysis of federal apparatus, and the semi-structured qualitative analysis from interviews of stakeholders' perception in the CCS subjects. The proposals involve energy policy actors (ministerial councils, ministries, and federal agencies for the oil industry and environment). The cost of complex arrangements for dealing with climate change policies should be considered, despite the absence of the CCS technology in the political agenda. The Current policies may ponder the constraints for increasing consumers costs in electricity, low-hanging fruits in the bioenergy sector in its carbon market (RenovaBio), and the role of fossil fuels in the energy transition.

Chapter 9 presents a broad discussion through previous chapters, and the conclusions of the thesis.

1.4. CHAPTER 1 REFERENCES

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2. CLIMATE CHANGE REVIEW AND THE CCS TECHNOLOGY CONTRIBUTION TO THE CLIMATE MITIGATION CHALLENGES

2.1. INTRODUCTION

The changes in climate patterns observed in the recent geological epoch, the Holocene, have been pointed out as potential for negative impacts on health, social well-being, and the economy. Global changes can be observed in accelerating shrinking glacial environment processes, changing coastlines, average ocean

temperature, and indirect impacts, considering how it changes biodiversity maintenance conditions (IPCC, 2014a).

Human interaction ns with each other and with the environment have been responsible for abrupt changes at a regional scale, for example, those observed in lacustrine and fluvial environments (Chin *et al.*, 2017; Porinchu *et al.*, 2017; Schmidt *et al.*, 2018). The increasing greenhouse gas (GHG) emissions after the industrial cycle are pointed out as the primary cause vector, and it has become the subject of international negotiations in which several countries have committed to the climate mitigation challenge.

The carbon capture and storage (CCS) technology has been elected as a critical component to be adopted in the climate solutions, mainly for a given group of industries due to the CCS resilience of rapidly reducing current levels without significant negative impact on those economic activities the group of industries is involved (IEA, 2013, 2019, 2020a). This technology can be applied to capture the carbon dioxide currently released into the atmosphere by large-scaled stationary facilities, through the process of remodelling and revamping them, then transporting and injecting the capture GHG in the adequate geological formations for the permanent sequestration (IEA, 2013).

However, the assurance of committed countries in reducing their emissions has been difficult to accomplish due to a myriad of factors and actors involved in the decision-making process, such as production chain interactions between various agents or between them and other sectors, having an unclear distribution of gains, income, costs, and losses in the long-term.

This allocation of responsibilities, benefits, and costs along production chains has been a complex function in societies engaged in climate change policies. They embed exogenous variables for the decision-making of agents who, even high GHG emitters, supply essential goods for society and provide significant well-being gains, despite the lack of emphasis on climate policies.

This chapter will discuss a historical view between climate change diagnosis based on geological data and the decision-making process in the face of global warming by countries and discuss the CCS technology contributions and challenges as a crucial tool for climate change challenges in society.

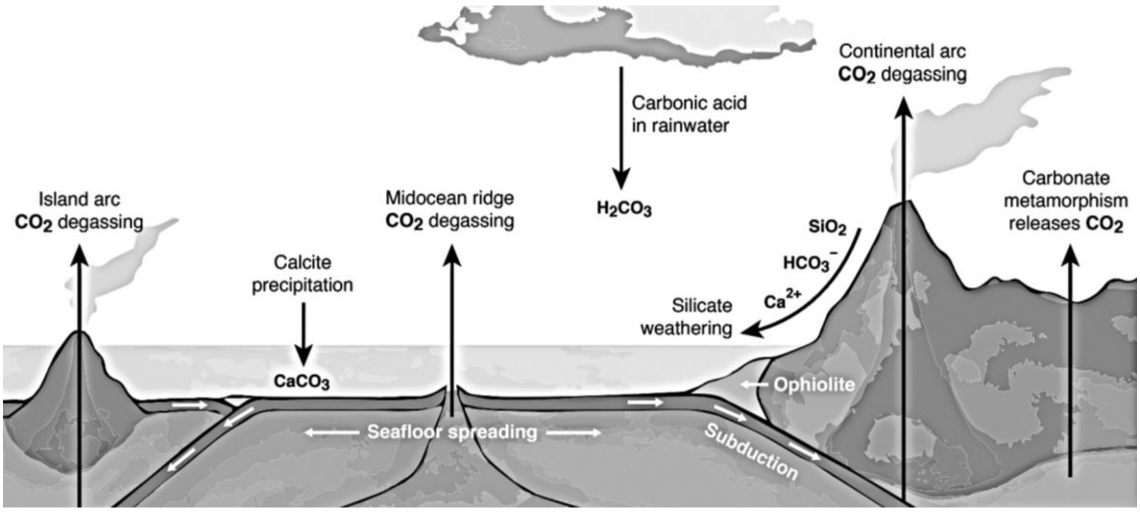
2.2. CLIMATE CHANGE APPROACH FROM GEOLOGIC CARBON CYCLES

The first consideration to be underlined is how the carbon dioxide enters the atmosphere and the mechanism to remove it back to the crusts, the sea, or the soil.

The carbon flow on shallow layers of the Earth can be represented by mass flow via metamorphic processes, which results in the degassing of the crustal rock under metamorphism and the migration of carbon in the gas form to the atmosphere, by precipitation, in which it migrates from the atmosphere to the continental area and the ocean (ionic form); and by interchange due to the reaction between the seawater and its ocean floor (solid form, such as mineral phases of silicate), and vice versa (Berner *et al.*, 1983; Condie, 1997). There is also a contribution by tectonic processes and the biological system, being natural sources of carbon exchange with other environments (Condie, 1997).

The figure 2.1 illustrates the carbonate-silicate cycle (known as the inorganic carbon cycle), the elements represented as essential components controlling the carbon dioxide equilibrium system from crustal zone to atmosphere. From it, the first consideration to be highlighted is how the carbon dioxide leaves the atmosphere and the mechanism to remove it back to the crusts, the sea, or the soil. Beyond that, the metamorphic process also contributes to the carbon cycle via the carbonate-silicate reactions or recycling process; the carbon dioxide migrates as $H_2O.CO_2$ through the rainwater, in the molecular form of an acid responsible for the weathering process in the long timescale, for the shallow dissolution rocks, including carbonate that insignificant input amount of carbon dioxide in the atmosphere, and, in short-term, for carrying to the ocean carbon and other by weathering by-products that improves carbonate precipitation in the seafloor due to the organic activities, followed by a reworking process and the transport to the subduction zone, leaving the small superficial system (Kasting, 2019).

Figure 2.1 *Main components of the Earth carbonate-silicate cycle and its sources for the atmosphere system. Geologic and biologic processes were the most important contributors to the carbon flow.*



Source: KASTING (2019).

The volcanic degassing process remains an important natural source of carbon dioxide and other gases to the atmosphere and the ocean. This mechanism releases volcanic gases in the atmosphere by tectonic events through time and inputs directly to the ocean by hydrothermalism in the submarine volcanos (Santana-Casiano *et al.*, 2016).

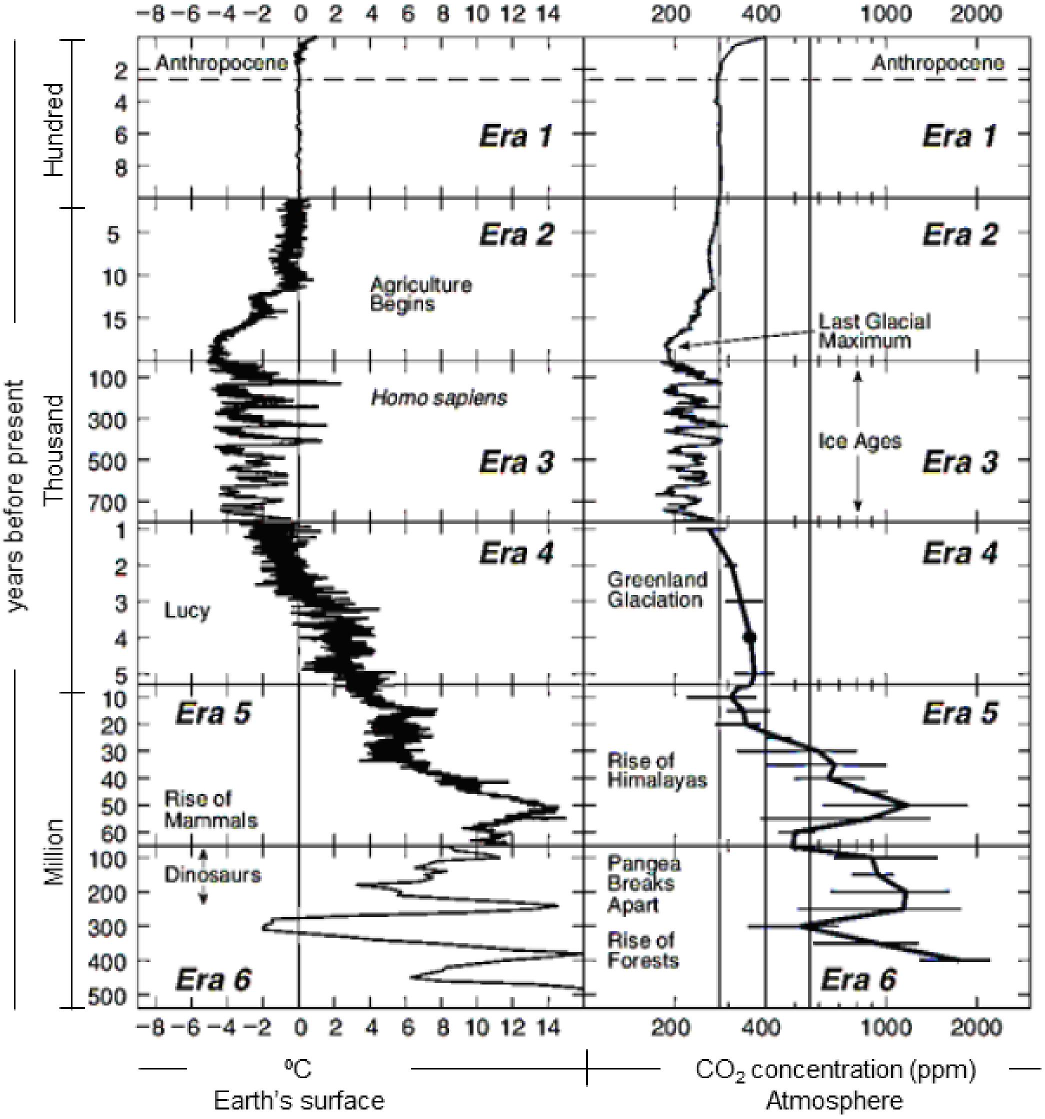
Among the natural processes, it can highlight those linked to volcanism, which is pointed out as responsible for the sudden increase in the concentration of carbon dioxide in the atmosphere during the Ypresian, in the Eocene (Pearson and Palmer, 2000; Storey *et al.*, 2007), and those linked to biological processes, such as the transition to the resurgence of polar glacial formation and its expansion, in the transition to the Oligocene (Pearson *et al.*, 2009; Speelman *et al.*, 2009).

As a system of equilibrium in the long timescale, the carbon cycle would tend to capture molecules from the atmosphere to the ocean and its inert deposits on seafloor via mineral form, through dissolution process, mitigating the effect of carbon dioxide concentration in the atmosphere.

In the Anthropocene, however, fossil fuels have played a significant role in determining the concentration of carbon dioxide in the atmosphere in a short time, such that systems capable of balancing the exchange system could not absorb the new stock transferred into the atmosphere (Crutzen, 2002; Paul J. Crutzen and Eugene F. Stoermer, 2000).

The history of terrestrial climate change over the past 500 million years can be illustrated in Figure 2.2, in which it is correlated the carbon dioxide concentration in the atmosphere through the geological era and the critical events that shaped it.

Figure 2.2. *Historical evolution of the Earth's climate. On the left side, the anomalous temperature of the Earth's surface considering average relativity for the 0 ºC equivalent to the preindustrial period's baseline.*



Source: Salawitch et al. (2017).

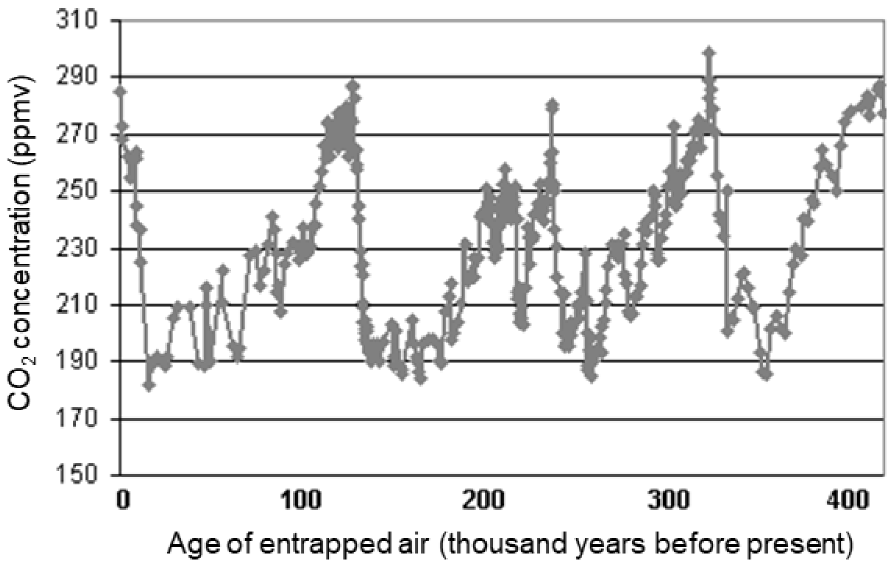
The first studies have provided comprehension about the ancient composition of the atmosphere based on geological records, and it impacted the study of climate (BARNOLA *et al.*, 1987).

Analysing an ice core that was drilled up to a depth of 2,077 meters, whose location was the Vostok Glacier in Antarctica, it was interpreted that the concentration of carbon dioxide along the profile sampled was correlated with temperature records. Given the accuracy of the correlation between hole depth and history of atmospheric composition in a complete glacial cycle (BARNOLA *et al.*, 1987, WUNSCH, 2004).

The research was expanded through a new drilling hole, whose maximum depth of 3,300 meters was correlated with the age of 420,000 years and 417,000 years respectively for ice and air trapped molecules (Rothman, 2002), and similar data found elsewhere besides the Antarctic continent (Deji *et al.*, 2017; Klein *et al.*, 2016; Petit *et al.*, 1999; Thompson, 2000) as well as its correlation with global warming (IPCC, 2006; Seip *et al.*, 2018; Yamamoto *et al.*, 2012).

Briefly, glacial-interglacial cycles were observed defined at a periodicity of 100,000 years, with carbon dioxide concentration in the atmosphere of up to 300 ppm in a natural glacial cycle (Figure 2.3).

Figure 2.3. *The Vostok drilling hole's Carbon dioxide concentration, in parts per million in volume (ppmv). The data allows illustrating the last four glacial-interglacial cycles, in which concentration ranged between 190 and 280 ppm of* CO_2*.*



Source: https://cdiac.ess-dive.lbl.gov/trends/co2/graphics/vostok.co2.gif. Access: Nov 26th, 2020.

2.3. UNDERSTANDING ANTHROPOGENIC GHG SOURCE ON GEOLOGICAL ERAS

The human-Earth interaction brought about changes in the environment of sufficient relevance for a new division in the geochronological stratigraphic chart to be discussed. Previously, the current time was framed in the Holocene, a time marked from the last glaciation, approximately ten thousand years old, and already under the effect of human interaction and environment, however, with negligible proportion. The agricultural processes by individuals, the increase of the global population, and the consequent urbanization, per se, would motivate the improvement of the time global scale within and beyond the Holocene epoch (Zalasiewicz *et al.*, 2017).

Previous research allows inferring the need for a better understanding of the effects of human activity interventions on the environment in both time and space. It has been proposed a subdivision on a geologic time scale based on a markable discontinuity of oxygen isotopes on stalagmites of the Meghalaya cave in India (Marsh, 1864; Walker *et al.*, 2018), whose point that the cause was a climatic related event with an abrupt change of climate conditions at the beginning of the Holocene, as well as its markers of Greenlandian, Northgrippian and Meghalayan stages/ages – 11.7, 8.2 and 4.2 thousand years, respectively. Concurrently, the suggestion of including an appropriate geochronologic classification to present-day global changes, which happen faster than usually observed on the global geological cycle, was discussed by academic research, maintain similar scientific criteria in terms of reasonability that surrounded another time scale.

Global Boundary Stratotype Section and Point (GSSP) represents the visual record in a given geological stratum, correlated globally, therefore, without representing only a local or regional change in the conditions of formation and deposition of sediments, and such marker should define a reference point in a geological section and specific locality, called Golden spike (Zalasiewicz *et al.*, 2017). Discussions on the recent geological epoch, the Anthropocene, emerged as the period in which the exploitation of natural resources in number and per capita expands in such a way that it modifies future geological records in the form of GSSP and, for instance, indicates a group of climate changes incompatible with natural behaviour that will last for the next fifty thousand years (Crutzen, 2002; Paul J. Crutzen and Eugene F. Stoermer, 2000).

The theme's complexity led to creating the Anthropocene Working Group (AWG) to answer age hierarchy and markers questions. According to the AWG, these discussions[1] include changes in carbon dioxide, methane, and nitrous oxide concentrations in the atmosphere, changes in the isotopic ratio between continental and marine carbon, on physical patterns of the sea, all of them linked to the atmosphere (Zalasiewicz *et al.*, 2017).

For the AWG, regardless of the previous effects of human action, only in the middle of the 20th century was the first synchronous and clear marker of the transformative influence of human beings on the main processes, physical, biological, and chemical, on a planetary scale. Preliminary Anthropocene results suggest an Epoch hierarchically positioned after the Holocene, having as a temporal marker the middle of the twentieth century, the plutonium fallout caused by main human activity and affecting albedo in the polar regions (Zalasiewicz *et al.*, 2017). Despite plutonium marks proposed by AWG, suggestions for the Anthropocene marker as the end of the 18th century remains latent since it represents the period of increasing global concentration of carbon dioxide and methane in the atmosphere began (Crutzen, 2002). The definition of a new geological Epoch remained opened by geoscientists; nonetheless, it is emphasized that the GHG emission growth after the industrial era is directly correlated to human activity, and it might be correlated with a possible new geological epoch.

Approximately in 1950, a virtually exponential increase in key socioeconomic parameters has been observed: population growth has achieved

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[1] Based on the preliminary recommendation of the AWC, the proposal of a new epoch that will come after the Holocene has been on the analysis by scientists of the International Union of Geological Sciences. Until it is not broadly accepted, the Holocene continuous to be officially the current geological epoch.
Informally, the Anthropocene has been used to highlight the diachronous impact of humans on Earth. This paper will take the freedom to adopt the term much more in this informal path.

unprecedented levels, as well as the levels of urbanization and production necessary for the new demographic profile, such as the significant increase in fertilizer consumption, on energy, on international tourism, on transportation, on telecommunications or even on large dams (Steffen *et al.*, 2015).

Concerning fewer signs of environmental changes, it can be pointed influences of recent human interaction with the environment.

One of the is the changes on the aquatic ecosystem in the western region of the United States of America has been interpreted by analysing the Linkins and Grizzly Lakes microfossils, in which the rate and the magnitude of fauna renewal observed in the early 20th century exceeded those observed in the older samples, resulted from the organic production increasing due to warming process (Porinchu *et al.*, 2017). Moreover, the land-use changes and occupation may lead to relevant river modifications, such as the western Chinese rivers in which the proportion of cultivated land was directly proportional to the increasing in contemporary sedimentary load compared to the sedimentary load generated (Schmidt *et al.*, 2018). Similarly, there is a wide possibility of diagnosis regarding human-induced environmental changes, which allow changes on acceleration tendency of human action effects on the environment (Chin *et al.*, 2017; Steffen *et al.*, 2015).

Given the diagnoses, climate issues began to occupy the governmental agenda. By resuming the global warming theme as a focal point, it is possible to understand the emergence of the appeal for mitigating measures. After the beginning of the industrial period, the concentration of carbon dioxide in the atmosphere increased approximately 50%, reaching 420 parts per million (ppm) of carbon dioxide in the atmosphere, significantly increased in the last two decades. Human activity is among the most significant contemporary challenges to be confronted, engaging agents to look for technologies that allow the reduction of carbon dioxide emissions levels in the atmosphere, the changes in production and consumption patterns to achieve a global scaled low-carbon economy (IPCC, 2014a).

The CCS technology is one of the eligible mechanisms that are capable of providing a significant contribution to offset carbon emissions from anthropogenic origin. As part of the climate change solution, this technology has been targeted within a portfolio to reduce carbon dioxide emissions from fossil fuels and the hard-to-reduce industries (European Environment Agency, 2011; IEA, 2011a, 2013, 2019). However, the complex paths between the conceptual CCS application and the concrete implementation of economic production chains and its global effects intersectoral, observing how the CCS can impact the other economic chains, remains as a decisive barrier.

2.4. THE CONTRIBUTION OF THE CCS TECHNOLOGY TO TACKLE CLIMATE CHANGE MITIGATION CHALLENGE

The GHG emissions can be combined into two segments: natural and anthropogenic. The natural emissions include all processes related to biological activity, native vegetation, and natural processes of burning, reforestation, and decomposition of biomass counting diagenetic and metamorphic processes on geologic formations (Condie, 1997; IPCC, 2014a). The anthropogenic emissions cover those resulting from human activity, especially the burning of hydrocarbons, those linked to agriculture, forests, land-use changes, and industrial processes.

Within anthropogenic sources, GHG emissions could happen in stationary sources over time, such as thermopower plants, large industrial clusters of chemical, petrochemical, refining and fertilizer manufacture, cement and steel industry, which represents a punctual and local concentration of high emission level. They are named stationary sources (McQueen *et al.*, 2020; Millar and Allen, 2020).

Another situation can be characterized by the severe difficulty of reducing their emissions, migrating to a low carbon economy and being resilient to the significant changes in their behaviour, such as operational thermopower plants, industry, and transport sectors.

The industry and the energy sector can be directly qualified in both criteria, stationary and hard-to-reduce their carbon footprint. Both sources can be classified, directly or indirectly, as challenging to decarbonize and stationary, and emissions linked to them have been of complex resolution only through international climate agreements.

From the 21st Conference of the Parties (COP) agreement – The Paris Agreement –, the need to promote the concept of incentive mechanisms[2] for each economic segment emerged, particularly for large-scale stationary sources without the institutional capacity to adopt appropriate climate change behaviour unless external gain factors allow dealing with decarbonizing long-term costs.

The dimension can be understood from the global view. In 2016, the annual emissions total was approximately 49.04 $GtCO_2eq$, being 33.1 $GtCO_2eq$ from the energy and industrial sectors distributed in several end-use sectors (UNCC, 2019), as shown in Figure 2.4.

There is the coupling of emissions by source and sector on the left side, which could be inferred as part of the link upstream of the production chain, intertwined with the other, for example, energy and transport. On the right, the graph shows emissions by productive activity or final use, which allows us to infer being downstream of the production chain.

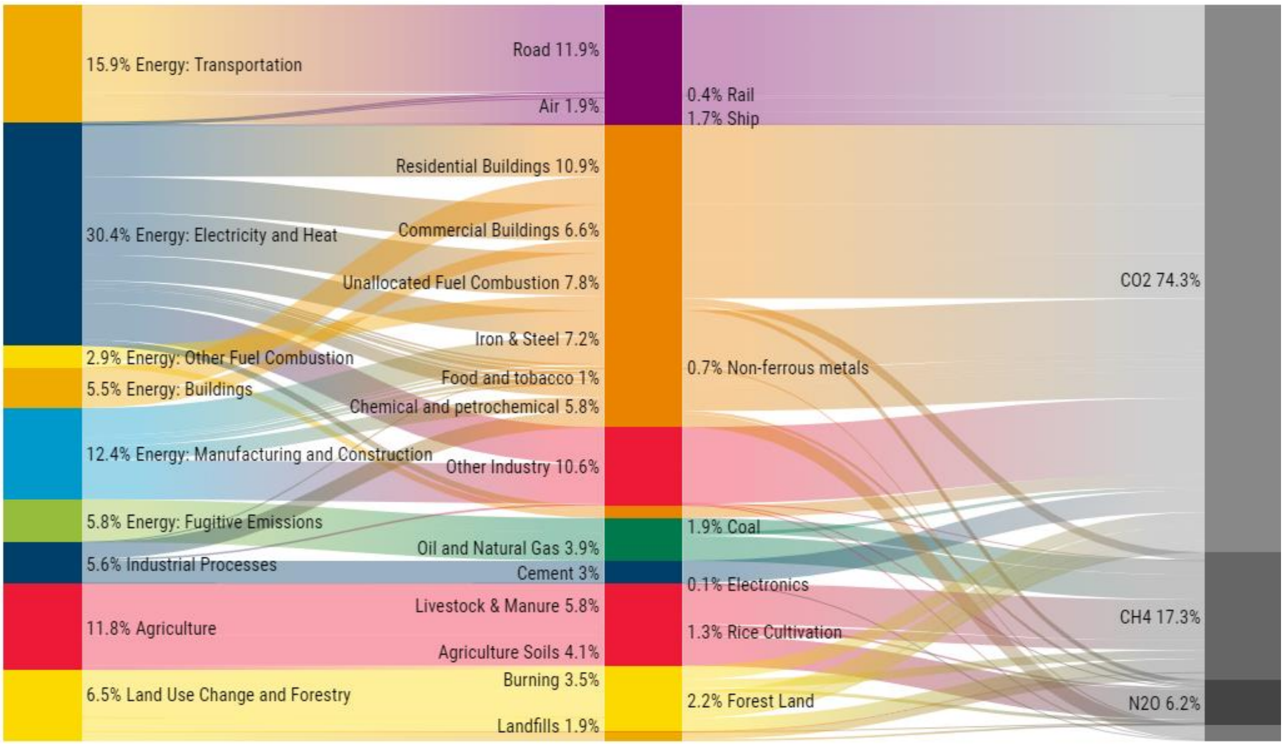
As a corollary, agreements that seek to modify the energy sector cause a spreading effect of improving the other end-use sectors. Besides, interventions in end-use sectors may affect the carbon footprint for final consumers, who would be, in elastic interpretation, the main impacted and responsible for emissions, from the final product's point of view. Hard-to-abate sectors, like steel, cement, dispatchable thermopower plants, long-distance transport, naval, and aviation added up together approximately 27% of AFOLU[3,] as shown in Figure 2.5, it fits the criteria of complex decarbonization emissions factories (Davis *et al.*, 2018).

In terms of cost, solutions are applied to make use of energy efficiency mechanisms, increase productivity on power generation segment and industrial

[2] The Kyoto Protocol also had mechanisms to incentivise carbon mitigation, although not specifically to CCS.
[3] AFOLU: Agriculture, Forestry, and Other Land Use

processes, and replace polluting fuels for cleaner options, such as the exchange of thermal coal for natural gas (IEA, 2017; Pee *et al.*, 2018).

Figure 2.4. *Stacking graph and the correlation between emissions by source sector (left) and end-uses (right).*



Source: HERZOG (2009).

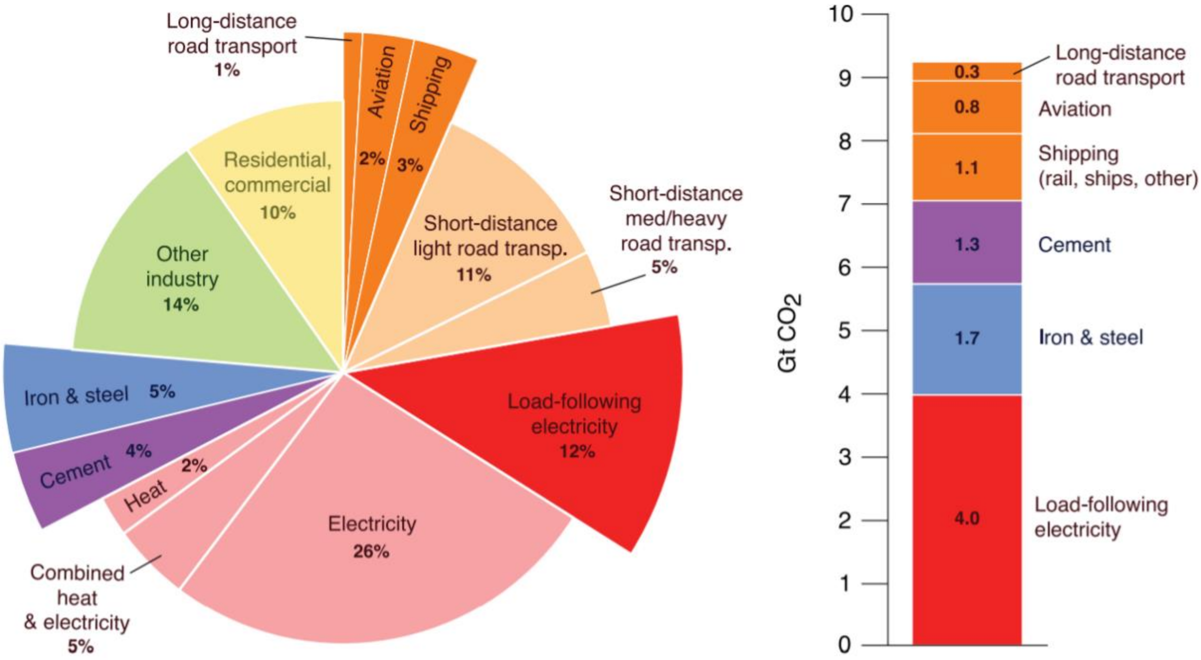
For ambitious targets set by developed countries, for instance, net-zero emissions in the European Union and the United Kingdom, intervention is needed to capture GHG emissions before reaching the atmosphere and its geological sequestration. CCS as a critical technology could contribute up to 14% of the total reduction of carbon dioxide emissions in the reference 2060' scenarios, and whose the majority contribution is the ability to allow capture process in the large-scale stationary sources economically feasible (IEA, 2020b, 2020a, 2019).

However, it is essential to adapt the legal and institutional rules to encourage their development in these segments to implement the CCS technology.

The absence of incentives probably may discourage an economy with low levels of carbon emissions.

In addition to the definition of a specific legal framework, it is necessary to adapt the network of governance, coordination, and cooperation between countries to understand acceptable practices in the conduct of operations and business necessary in the creation of the scalability of the CCS projects (Allinson *et al.*, 2017; IEA, 2017).

Figure 2.5. *Percentage distribution of GHG emissions. The featured plots (red, orange, blue, and purple) refer to the sectors based on final use resilient to decarbonization. The solution for mitigation in the current context includes direct CCS application in the factories and compensation via natural sinks or BECCS[4].*



Source: (Davis *et al.*, 2018).

Therefore, international climate agreements can lead to aprioristically change in the behaviour of decision-makers via soft power (Falkner, 2016).

[4] BECCS: Bioenergy with carbon capture and storage

Subsequently, they are encouraged to make changes in the new legal, institutional, and normative frameworks under their jurisdictions, intending to implement long-term guidelines that support the reach of a low-carbon economy.

Through the behavioural changing of the various agents along with the production and consumption chain, based on incentives and punishments aimed at reducing the general and unitary costs for society, and that pursues the equitable sharing of duties, in addition to the tax and credit capacity of the countries (Parties) signatories to the international treaty, and in a harmonious way between the present and the future generations (Falkner, 2016).

2.5. FINAL REMARKS

Pioneering studies on the effects of human activity on the Earth's climate, especially when compared to rapid growth after the industrial period to the same atmosphere, has raised political concerns about climate change caused by the increase in GHG in the Anthropocene (Barnola *et al.*, 1987; Idso, 1988; Seip *et al.*, 2018)and whose cumulative trajectory may become irreversible due to the importance of economic activities dependent on the energy sector.

From these discussions in society, several countries engaged and made decisions to reduce such emissions.(Barnola *et al.*, 1987; Idso, 1988; Seip *et al.*, 2018)

The form of embodiment took place through the international agreements, highlighting the most relevant, the Paris Agreement. However, they have not been effective in limiting emissions in this case. The complexity occurs because the issuing sources are incomparable directly, given that the costs involved, the maturity of the CCS projects, the accessibility of financial resources to modify the business's trajectory as usual, over and above the contractual, juridical and institutional frameworks involved.

The complexity, as mentioned earlier, could be the case of those sectors whose reduction or cessation of GHG emissions in an economical and efficient method and whose current choice of reductions by country rather than sectoral targets tends to make a choice incomplete or even tricky to achieve global terms.

Once the governments deal with hard-to-abate sectors into mature and complex production chains, the business groups try to bargain with public agents involved to postpone the solutions presented.

For that, organized groups with well-defined and firm interests have been characterized by the concentration of benefits on producers and the partition of costs between the whole society, whose conflict interest with the political body on a short term, and a residual uncertainty about the climate issue and make possible only political consensus on an incomplete solution. An urgent need emerged to establish regulation and economic incentives that adequately available resources, territorial realities, and limitations of existing national and international institutions on climate change. For them, the solution that proves feasible involves adopting carbon sequestration via the CCS technology, directly in their stationary sources of GHG emissions or through the BECCS as a compensation mechanism when the technical or economic impossibility of performing it directly at the issuing source.

Governments, therefore, are responsible for establishing suitable institutional rules and for arbitrating the available resources, the interests between the groups, adjusting costs overtime to those they will fund, and, as a result, deal with the problem of the long temporal gap between the cause (emissions) and the consequence (global warming).

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3. THE ROLE OF INSTITUTIONS FOR SHAPING STAKEHOLDER'S BEHAVIOUR IN THE CCS TECHNOLOGY DEPLOYMENT

3.1 INTRODUCTION

The carbon capture, transport, and storage (CCS) technology built its technical bases adjacent to oil industry much more related as a consequence than a target, and some industrial process in which the capture could be monetizable. However, recently it came back to the short-term political agenda as one of the paths to the GGR from fossil fuels (IEA, 2013; IPCC, 2014b, 2018a).

In the long-term, the Integrated Assessment Models (IAM) have pointed four main pathways to limit global warming to 1.5º with no or limited overshoot, by using Carbon Dioxide Removal (CDR) varying across them considering the relative participation of three main contributors. First, the substantial reduction of emission from fossil fuel and industry achieving more than 91% in all scenarios; the removals in the Agriculture, Forestry and Other Land Use (AFOLU), which might not achieve negative emission only in the P4 scenario; and the Bioenergy with Carbon Capture and Storage (BECCS), which might represent the critical vector of negative emission at the end of the century and the main CCS system applied in the climate challenge (IPCC, 2018b; Kriegler *et al.*, 2017; Rogelj *et al.*, 2018).

Although the potential of Greenhouse Gas Removal (GGR) by the CCS projects, considering the technological maturity, and the cost reduction, could partially solve Hard-to-abate industries, the most important potential remained being its application through BECCS (IEA, 2019, 2017; Kriegler *et al.*, 2017).

Researchers and the private sector recommended the need to incorporate a legal and institutional framework for the CCS business capable of promoting and encouraging economic agents to develop the large-scale projects dedicated to permanent carbon dioxide storage safety and feasible (Dixon *et al.*, 2015; GCCSI, 2019; Institute, 2014; Lipponen *et al.*, 2017; Rassool *et al.*, 2020; Zapantis *et* *al.*, 2019). Beyond the definition of the legal institutions, it has to incentivize the coordination between agents, the cooperation between countries, and the evaluation of environmental, social, and governance questions for understanding good practices applied to the new economic activity (Havercroft, 2020; IEA, 2009a, 2013).

Despite the existing legal improvement, the evaluation of institutions and how they affect the development of CCS technology in countries whose projects are more advanced points out to the arrangement of possibilities that allows us to improve from the learning-by-doing process, the cautions and recommendations to assimilate when building a new normative and institutional framework for developing countries to deal with significant CO_2-GHG stationary sources, such as in Brazil, Mexico, and China. Therefore, the institutional analysis may contribute to support public policies in the decision-making process.

This chapter summarizes the *neo-institutional* theories, and the analysis of their mechanisms to induce the long-term behaviour from trust perception and risk brought by the CCS large-scale projects. It may consider that the theory of institutions was developed based on multidisciplinary contributions, and in general, relates to the rules that govern the game in society and how they have repercussions, in contrast to classical economics, which was oblivious to the concrete reality and was based, at least at the time, on scenarios and abstractions that minimized these rules. Moreover, it aims to contribute to the current rules' comprehension and to enhance institutional analysis applied for the CCS business.

Its bases came from the academic adaptability of institutional theory to any politics, having bases in the interdisciplinary holistic view, in the economics as an open system susceptible to social relations, in the complexity that goes beyond the erroneous concept of maximizing utility by the individual that could in specific circumstances, stand out as the rational choice (Hodgson, 2000).

The temporal frame chosen is the 20th century's transition, when the rules' principles enter classical economics, when Institutionalism became formal by the exponents Thorstein Veblen, John Commons, and Wesley Mitchell, building the first Institutionalism. Later, the New Institutional Economics School became relevant, and the third relevant approach took place from the Institutional Analysis and Development (IAD), explained below.

3.2 ORIGINAL INSTITUTIONALISM, FROM VEBLEN TO MITCHELL

The notion proposed by Veblen (1994) to term institutions materializes as the habits of thought about particular interrelations and the individual rules in force at the community, having mutation characteristics over time, capable of reformulating and degenerating themselves, reborning from the individual habits in the community, named Original Institutionalism, without determinism and as a minority current of Institutionalism, created for response to the classical economic theories and in opposition to the marginalists (Veblen, 1994, 1909). Those habits tend toward the universal figure, instincts for parental inclination, work, idle curiosity, or just creative idleness (Murphey, 2017; Veblen, 1994).

From the individual habits that shape institutions, it is possible to change social directions and objectives from a new resultant social convention. Moreover, the understanding about institutions' autonomy arisen, and, with it, the influences of the causality' effect in the agent that allows people to be influenced by immaterial ideas, preferences, and behaviour, differing from the classical theory in which the deductive methods shaped institutions, institutions were shaped made more in deductive methods confirmed by empiric data than in the cumulative and complex process of cause and effect (Bateira, 2011).

From a broad definition, although intangible, the institutions are dynamic, fluid, and based on independent structures, moving away from the concept of being only the shared ideas and behaviours, or only the behavioural sum of each individual as a small economic, environmental unit. Thus, individual habits are the reproduction of social and cultural norms in which he was socialized, and, consequently, it would create social stability and resistance to institutional changes at the individual level (Veblen, 1994).

Before the World War II, another American researcher investigates the institutional trends, and he could apply his theories to the Executive branch. John R. Commons was a key institutional stakeholder, integrating the necessary contribution of the interdisciplinarity, the investigative method, and the reasonableness parameters' interpretation (Guedes, 2013); however, maintaining the opposite and individualistic character's view that underpinned the neoclassical theory (Hodgson, 2000).

Original Institutionalism provides an operative theory involving economic policy and legal framework, and the conflicts arose due to the habits already present in the society and in the human interaction, which caused goods' scarcity for specific agents, and the free market was not able to find a realistic solution over time that did not imply losses for the entire group once there remained the dependence among the various agents in the community that would present a disorder a warlike behaviour to achieve their goals (Hodgson, 2003).

Transactions can solve main problems, creates a relationship between agents (dispute), and establish appropriate and stable behaviour, by which individuals interact in their daily practice, governed by legal rules and customs in their *going concern* (Guedes, 2013).

The consequential concept of institutions encompasses the cases where mechanisms allowed the conflicts' solution, via transactions, and it would be linked to a remarkable entity, a strategic transaction, equivalent in the United States to the Supreme Court, which would be responsible for the arbitration of reasonable practices (Guedes, 2013; Hodgson, 2003).

Finally, we emphasize that institutions have autonomy and discretion that go beyond individual willpowers, regarding the collective action and its desires, like the fact that Commons disregarded institutions linked to undesired results of human interaction and self-organized spontaneous, alien to the legal system (Hodgson, 2003).

In addition, the public sector could be responsible for balancing losses and gains via arbitration and shaping institutions through time (Hodgson, 2003). Thus, the government would assume the metainstitution competence, a regulator position above the other systems, having the monopolist power to legislate, and whose control becomes the object of the dispute of the various groups organized into political forces (Bateira, 2011).

Also, within the Original Institutionalism, Wesley Mitchell embedded quantitative methods for the economic observation and a critical role of institutions (Klein, 1983). This understanding involved observing the results produced as an effect of institutions, standardized, on the collective behaviour of individuals, therefore involving the patterns and the regularities of the collective behaviour understandable within the institutions (Rutherford *et al.*, 1987). Lastly, studies that analyse the business cycles and the reconciliation of quantitative research and economic theory have corroborated the importance of its institutions for the countries' development (Rutherford *et al.*, 1987).

Summarizing the core contributions, individual comportment does not imply giving the shape of the institutions, but the set of habits and attitudes that guide them. In addition, similar instincts may promote different results due to the trajectories followed by the individuals' groups, the arrangement of institutions and the society improvement over time, and the interaction that motivates the agent for the maintenance or change of the economic institutions through implicit or explicit habits socially disseminated. (Bateira, 2010; Veblen, 1994; Zulian *et al.*, 2018).

The understanding of institutions goes through the methodological limitation of the sociocultural reality observation, and the economy cannot be the basis for restructuring it; nevertheless, the product of the diverse observations, quantitative and qualitative, that allows decrypting the institutions involved (Bateira, 2010; Rutherford *et al.*, 1987).

To conclude, the State would have the superior hierarchical function to arbitrate *reasonable* values in the conflict resolution, and thus it has to design desirable changes in institutions in the long term (Hodgson, 2003).

3.3 NEW INSTITUTIONAL ECONOMICS

Ronald Coase, Oliver Williamson, and Douglas North expanded the role of institutions, society, and economic development issues. The New Institutional Economics (NIE) sought to distinguish itself from classical economics or complement them by addressing the effects of transaction costs, the influence of the institutions, and the role of the contracts on the economic efficiency's path.

Transaction costs and the existence of firms played an important role in the development of the analysis from the institutional economics thought.

The economic efficiency could result from the performance of large firms, which would tend to have the gains of scale and the improvement of its production at a lower price than their competitors; however, the real price of the good provided by them was higher than the production cost due to other factors related to the transaction (Coase, 1937).

It can consider the hypothesis of perfect markets, in which the principle of economic efficiency results in the cost of production equivalent to a determined demand in the firm structure equivalent in the market, therefore, with the transaction costs equal to zero, and that, as a corollary, explains the existence of both, the firm and the transaction cost (Coase, 1937).

Furthermore, this research infers that the implications of transaction costs in society can add an essential approach to the institutional assessment and future climate change policies. The action of specific agents may have harmful effects on other components in a closed system, which would result in the use of the natural punitive legal instrument in the damaging agent.

In the high transaction costs hypothesis, the adoption of solutions to problems of the firms through courts, then the litigant should guide its decisions by the most economical and efficient solution, perhaps mutually beneficial, bargaining to reduce transaction its total costs, in other words, they should estimate not only the strict damage but the consequences in terms of social harm or even the potential gains comparing to the previous situation (Coase, 1960).

A similar analysis can be developed regarding the influence of economic instruments in reducing accidents and notions that went beyond the economic factor, such as the value of life in fatal accidents (Posner and Calabresi, 1970). In both cases, they established that the effective institutions are those in which the market tends to perform the total possible exchanges until the optimal cost-benefit is reached for the participating agents. The marginal exchanges do not increase the marginal utility of the whole group.

In this manner, the main contribution is the base for the Transaction Cost Theory (TCT), in which the rational choice of individuals beyond the evolutionary process of institutions aims to be assessed as far as high transaction costs get up and to proposed the reduction of transactional costs (Coase, 1960, 1937; North, 1990).

Besides that, Oliver Williamson (1985) developed the TCT from the previous basilar research to incorporate the contemporary characteristics, such as the classical economics realism based on the opportunism' concepts and the bounded rationality, the governance, and the need for the contracts facing the complex economic sectors and their uncertainties.

Within the TCT, the transaction costs are responsible for inducing the agents' behaviour, then, they can reshape the environment under the rational choice and tend to economic efficiency through the contracts establishing their specific rules that may cover contingencies and necessary adaptations throughout their validity (Williamson, 1985).

In terms of singularity, the contracts are designed from the assets that they are governed by (in this case, it covers particularities of all contractual nature), the frequencies they occur in terms of the transaction (for instance, adhesion contracts or very personal insurance as possible frequency extremes), and the uncertainties (Brousseau and Glachant, 2008). Uncertainty refers to the prospective or the even unpredictable scenarios, and it tends to be inversely proportional to the contractual gaps to be transacted according to need, i.e., the more unpredictable, the greater the need to avoid contractual gaps to mitigate the conflict or the opportunism of the parties (Williamson, 1979).

The occurrence of the opportunism, recognized as an undesirable behaviour that tends to increase individual welfare at the expense of others, is linked to market failures in the formal and informal institutions, in which the current framework is not able to ensure that the transactions made by the agents will effectively adhere to the contracts (Williamson, 1985).

The bounded rationality or the rules in force make the benefits of non-compliance higher than its present costs (Williamson, 1985). In general, it occurs because the agents do not have access to the same information as the others involved, and when the result is dependent on a diversified group of individuals, who contribute with the high cost and immiscible inputs, then they may be induced to opportunism (Williamson, 1975).

Several governances, corporate, or contractual arrangements can be used as a way to reduce transaction costs as a mechanism to mitigate such deleterious effects, even in the environment of bounded rationality that requires an underpinning for their implementation, such as the power to enforce legally accomplished contracts (Williamson, 2005, 1985, 1979).

In the governance structures, there were three types established by Williamson (1985, 1991) that can be summarized as:

i. Govern by markets, which combine pressure via competition and the appropriation of income flow, and which operate under price-based contractual mechanisms;
ii. Govern by hierarchies, whose agent's behaviour is subject to the hierarchical relationship of authority, exchanging contractual exchange mechanisms for internalization under the same firm, but maintaining devices that allow adaptation and division of responsibilities; and
iii. hybrids, based on long-term contracts and mechanisms for dealing with the uncertainties.

Therefore, it is inferred that Oliver Williamson's contributions consolidated some of the foundations of the NIE through the TCT and the contractual mechanisms as a path for institutional development over time to mitigate uncertainties in contracts and thus combat opportunism, which is manifested when such instruments fail.

Understanding the nature of institutions and how they disturb the economy's performance through their effects on the production and the costs of exchange was the research subject of Douglas North (1990).

According to North (1982), the institutions represent the set of rules of all kinds, such as the behaviours, the procedures, or even the moral or ethical rules to prevent the adoption of individual behaviour that maximize the wealth or utility of the principal, being responsible for defining the exchange relations between the principal and the agent, via formal or informal contractual relations.

Studies focused on the United States demonstrate the establishment of the organizations and the institutions from the rationality and the neoclassical economic theory’s constraints, and, thus, it shows that changes in the organizations based on the individuals’ rationality aimed to maximize their own benefits (Davis and North, 1971).

The main role of institutions was reducing uncertainties, establishing a stable structure for economic development, remaining them in continuous evolution, and altering the agents' possible routes (North, 1990).

This evolutionary process is highly complex since the marginal changes may occur due to changes in rules, informal restrictions, or the effectiveness of their application (North, 1990). Moreover, despite the possible abrupt change in the formal rules through the political and judicial processes, the informal restrictions already incorporated were more impermeable to abrupt change (North, 1990).

The transformative process of institutions in the economy can be shaped through changes in relative prices, which would act as incentives for the efficient institutional paths; through the lock-in between organizations and institutions, once the first prospered as an effect of the incentive structure of the second; and through the feedback on the changes promoted in the institutions and the interaction with the environment (North, 1991, 1990).

An institutional matrix that produces lock-in may present interdependence among the organizations and the consequent externalities, which implies increasing yields. Consequently, the profit of a given activity becomes linked to the institutional constraints promoted by the incentives around the structure.

However, opportunities arise from the political decisions with unintended consequences, which makes them the result between the costs and the benefits or the reduction and the increase in the economic productivity, mixing them into a single package, favouring the perception of the political and economic organizations from the path to the marginal and incremental changes in the existing structures (North, 1990). Although they may be subjected to evolutionary processes, this choice is quite evident in the case of the institutions that have the attribute of stability because the transformations they are imposed are not unexpected and abrupt, and the nature of the incremental and decision-making under the asymmetric information makes the institution changes follow to path dependence, as observed in the energy industry over the last decades (Fouquet, 2016; North, 1991).

3.4 THE INSTITUTIONAL ANALYSIS AND DEVELOPMENT FRAMEWORK (IAD)

The previous research preceding the IAD focused on the dilemmas of the individual’s behaviour and the common goods, most notably the collective action theory and the tragedy of the commons (Hardin, 1968; Olson, 1965).

Both theories considered that individuals would face challenges in organizing themselves for the collective common goods and would tend to act through groups in defence of their own interests and to use the institutional capacity than actions that aimed the collective interest (Olson, 1965).

The tragedy of the commons, in addition, would face barriers that input a complexity overlapping individual welfares, in which the abuse the common good by the agents may cause the exhaust disease unless there is an arbitrage by the State or by private management of the goods shared (Hardin, 1968).

This result is coherent to the agents' inability individually to adopt short-term individual benefits behaviour, in the governmental coercion' absence through regulatory tools, even being harmful to others participants (Ostrom and Ostrom, 1971).

As an alternative to the mainstream mentioned earlier, The IAD school required to cover the dispute mechanisms (rules) developed by local communities and the users of the property that allowed the (self-)governance of shared natural resources, that could be applied to the natural resource systems as large as the cost to try to exclude the potential beneficiaries able to use them, establishing the Common-Pool Resource (CPR) definition (Ostrom, 1990a).

For them, under favourable conditions, the local community is capable of carrying out the sustainable management of the local natural resources available. In summary, the IAD has advocated, as much as possible, that the direct negotiation between the interested and affected agents can result in lower transaction costs even without a state' intervention, considering the management through local institution can be more effective than rule-setting by central government (Ostrom, 1990a, 1990b). In addition, it aimed to assess mechanisms to reduce the means of deteriorating local institutions and the way to shape them and achieve expected outcomes related to self-organization, self-government, and long-term institutions through the bottom-up organization (Ostrom, 1990a).

Under these models, fewer studies have been developed involving CPRs, such as coastal fisheries, irrigation systems, common-use grasslands, and groundwater exploitation, and they illustrate how secular institutions that have prospered have similarities and how fewer of them have been unsuccessful, such as the structure of monitoring by users effectively, and the Californian groundwater governance system fails (Ostrom, 1990b).

The possible reason is that institutions depend on theoretical work at three specific levels — development of systems or structures, theories, and models — whose application depends on the issue under the analysis (Ostrom, 2011). The main IAD applications have been for theoretical analysis of institutional framework. The specialist maps the main elements and their interdependence and performed prescriptive diagnostics to provide metadata that allows the identification of universal elements or phenomena to compare theories that contemplate the institutional development (Ostrom, 2011).

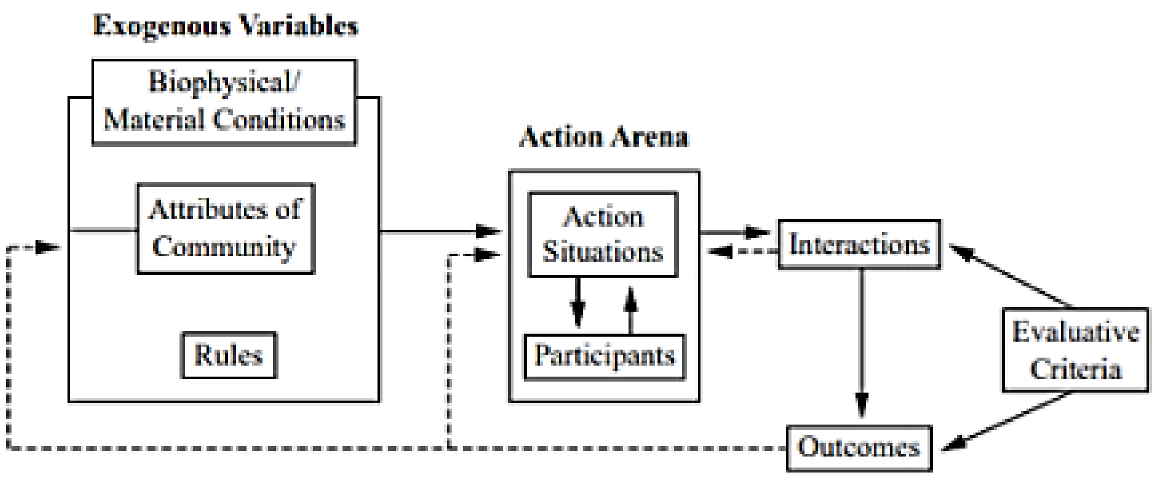
Several analyses compromise the consecutive proposition of institutional arrangements or even the inference of the most appropriate institutional phenomenon to the case by failing in the diagnosis. Then, a secondary but essential outcome for the IAD is avoiding the use of inadequate models, that is an achievement of important guidelines, such as the flow of activities performed by the agents, the costs analysis, and to whom the benefits are addressed (McGinnis, 2011; Ostrom, 2011).

The definition of the action situation can be considered an IAD's innovation. It focuses on the analysis involving the actors, the organizations, the available information, the preferences, and the interaction among them, such as the exchange of goods and services, or even the conflicts, and its potential outcome (Ostrom, 2005).

According to Figure 4.1, it is possible to identify patterns of the actors' interaction and to assess the outcomes of its relations; however, the conflict can emerge at the operational level, in which the final product results from local incentives tactile and well-known by the actors (Ostrom, 2005).

It is the possibility to found conflicts at higher levels of the decision-making process, for instance, in the public policy formulation, the object of behaviour assessment, of resources analyses or individual action' patterns before performing the institutional analysis to understand the framework of the situation and its adaptation process over time (Ostrom, 2011).

Figure 3.1. *The IAD framework.*



Source: extracted from Ostrom (2011).

The results' prediction is complex and dependent on the uncertainties' decrease. On the hypothesis of being unachieved, the hierarchy relationship can inhibit opportunistic behaviour, which can enhance this problem in decision-making and affect the environmental rules and its characteristics, such as the trust in the institutions (Ostrom, 2011; Williamson, 1985).

Moreover, the agents that operate in the same sector can, with time and experience, mitigate the damaging effects of complex markets and their market failures, such as the incomplete and asymmetric information challenging to integrate into the decision process (Walker and Ostrom, 2009).

The work rules also shape individuals' actions by defining requirements, prohibitions or permissions, implicit or explicit, and predictable to be understood and incorporated by different groups when they adopt a position in the arena (Ostrom, 2011). In several countries, such rules materialize through a framework supported by legal, constitutional, and normative apparatuses.

For the IAD, this legal framework needs to provide a minimum set of rules necessary for the agents to understand their actions, based on those previously in use by the individuals, and in a way that orders the relationship between participants within the action situation (Ostrom, 2011).

Even under the rule of law, implicit rules remain relevant, given that the institutions formed have changed with time, and such rules undertake an informal character and an almost instinctive understanding by the agents, which demands a relative effort to comprehend them when conducting institutional analysis (Ostrom, 2011; Ostrom and Ostrom, 1990).

In a systematic effort, Ostrom (2011) classified rules with the following arrangements:

i. boundary: defining the rules of who can participate in the action situation;
ii. position: relative to the decision-making hierarchy within the group (whether it is just one member or someone with high decision-making power);
iii. scope: defines the geographical limits within the dispute or work rules apply;
iv. choice: issues concerning the technological option rules for the exploitation of the natural resource's target;
v. aggregation: refers to the mechanism to prioritize rules when needed;
vi. information: defines what can be publicly known or kept secret;
vii. payoff: incorporates the group of sanctions applied to those who break the rules, the monitoring, and the conformance to it.

In the outcome assessment, the IAD can use several metrics to interpret whether it achieves the intended purpose, which includes economic efficiency and redistributive efficiency, fiscal equivalence, transparency, or even sustainability (Ostrom, 2005). In general, the trade-offs analysis can gain prominence for the performance assessment and the alternative institutional arrangements’ choice. For public goods, the efficient price equivalence to the marginal cost of use means zero, which sets up a problematic concept for climate change and public goods, and occasionally represents perverse incentives and potential inefficiencies. To this end, the analytical diagnoses of institutional arrangements and the predictable trade-offs among intermediate costs can help to find alternative solutions beyond the climate change assessment trap (Ostrom, 2011).

By combining appropriately rules, and regarding the potential of reshaping agents' behaviour, the CCS system may work as a CPR, for instance, stablishing boundaries to be followed by emitters, enforcing them to act collectively to prioritize the target of net-zero emission in the geographic limit or the economic chain they work.

3.5 INSTITUTIONS, CLIMATE CHANGE, AND THEIR IMPLICATIONS FOR THE CCS'S PERCEPTION OF TRUST AND RISK

In the hypothesis of perfect markets and its transaction costs null, the bargaining power would not affect the outcome efficiency (Coase, 1937); however, it does not work correctly in the economic sectors that the transaction costs are positive, especially in the indivisibilities and the irregularities that characterize the myriad institutions, which outline the long-term economic change (North, 1990). The parameters of economic efficiency may help to adopt decisions whose integral effects are beneficial to the various organizations sharing the arena, even when fewer agents are not entirely successful in their demands, such as in the current carbon pricing mechanisms for climate change (Boyce, 2018; Coase, 1960; Daggash and Mac Dowell, 2019; Kaufman, 2007; Zweifel *et al.*, 2017).

The institution's effectiveness in reducing transaction costs, their malleability degree, and the agents involved, they respond to changes in the preferences and in the relative prices that determine this environment, mainly when they are done incrementally in a stable institutional model as a way to avoid unwanted effects caused by abrupt changes (Brousseau and Glachant, 2008; North, 1990; Williamson, 1985).

Fewer schools argue that the agents involved in CO_2-GHG emitting activities would tend to adopt short-term individual economic maximization behaviour, configured as the tragedy of the commons, where the State would have an arbitration role over such agents' actions (Hardin, 1968; Hodgson, 2003).

From the Original Institutionalism, it may use the concept of the State as a regulatory metainstitution to be disputed by the political parties in order to maintain the evolutive institutional order and to find the conflict solutions on reasonable terms within the desirable changes in the institutions (Bateira, 2010; Hodgson, 2003; Veblen, 1994).

In terms of the NIE, the contracts would be responsible for solving the conflicts between parties, and the govern (public sector) must keep the custody and to manage the preferences of the agents incapable of obtaining and process enough information and so to adopt actions following the Theory of Rational Choice, which put the State hierarchically in the superior position to the organizations, giving the advantages of precedent order in the decision-making order, and, as a consequence, enhances the rigidity of maintaining the institutions' trajectory over time (Fouquet, 2016; North, 1990; Williamson, 1985).

In contrast, the IAD contests the State's prominence over local authorities or agents, emphasizing the local competencies in shaping the relevant institutions' long-term collective needs. Thus the complementary State's role for issues that go beyond the local boundaries cannot be achieved through rules and incentives (Ostrom, 2011, 1990b).

Discussing the State's role and climate change challenge, it is possible to find a myriad of hard-to-assess and intertwined decisions. The distribution of responsibilities, benefits, and cost allocation along the production chains has been a complex function once they introduce exogenous variables to the decisions process to provide a balance between social welfare and GHG emission.

Thus, there is support for the State needs to act as a higher hierarchy agent that wants to change the agents' behaviour by operating rules in the hard-to-abate sectors, to build decisions that better integrate the desired results and that prevent opportunistic behaviour (Williamson, 1975), allowing robustness to adapt to the technological challenges, despite the complexity of changing trajectory before political decisions (Fouquet, 2016; Unruh, 2000). In this case, the institutional analysis should focus on efficiency and environmental protection concepts to achieve the GGR scenario under reduced transaction costs by improving existing rules rather than creating new unknown and unverified frameworks.

As a potential economic activity and a tool to support the GGR challenge, the CCS technology is consistent with the institutional analysis for the infrastructure sectors, in which the capita-intensive and the long-maturing characters input complexity in the valuation models and the marginal costs (Bui *et al.*, 2018; Zweifel *et al.*, 2017).

Moreover, the IAD allows assessing the sectoral specificities to avoid CO_2-GHG cap systems that neglect the regional concerns, the resource availability, the local native skills, or the CCS activity as the contiguous hard-to-abate sector under the challenges of the current fragmented regulatory framework, especially in defining risks and responsibilities in its activities and the consequent behaviour' incentives for the institutions facing the GGR. Having appropriate conditions and rules, the CCS business may work under a CPR proposed by Ostrom (1990b)

The risk and the economic viability of a project that aims the GGR associates with the uncertainties above-mentioned can be incorporated into the institutional concepts of politics and regulation.

Legal and regulatory instruments are the product of the various social vectors at the political arena of the Legislative and Executive branches, and they allow to improve the CCS acceptance and legitimacy.

A well-defined game's rules may reduce uncertainties and costs inherent to the risk of immature activities (Meadowcroft and Langhelle, 2009). Generally, legal models have been designed considering incremental fragmented policies, remaining prospective gaps, liability, and property rights that tend to be essential regarding risk mitigation and decision making in the CCS activity (Markusson *et al.*, 2011).

Regarding the technology readiness level (TRL) of the CCS, the energy economy currently penalizes the established technologies through the infrastructure and technology lock-ins.

In the technologies in which the TRLs are lower than 5 (component and breadboard validation in relevant environment) the energy penalty is still high, creating a solid gap for the development of a new business, or economic barriers for those TRL between 6 and 8 (system completed and tested through demonstration and pilot projects). In both cases, the process of enhancing institutions needs a hierarchical aspect to put agents on adequate conditions of desirable behaviour. The role of the public sector, for TRLs lower than 5, can be incentivizing research and development (R&D) for basic science, internalizing positive externalities from public investment, and, in the second, to promote pioneers' projects and pilot plants to allows them to reach the learning curve for the commercial scale in economic bases, for instance, on industrial sectors in which low-hanging fruits are not available.

In the middle of the CCS business chain, the transport may represent an important gap from the capturing process to the carbon dioxide final disposal due to the monopolistic attribute. Seeing that agents may not change how they behave instantly, the public sector must take on the commitment of planning, regulating and incentivizing the deployment of carbon hubs, from capture clusters to the final storage geologic fields.

In conclusion, we can infer that, uncertainties aforementioned in the literature can be summarized as follow:

i. The political, regulatory, and policy decisions, such as the CCS incentives, the carbon pricing, the long-term GGR targets, and the liability, significantly impact the cost-effectiveness and the projects financial viability;
ii. The absence of a regulatory framework reduces public confidence, and it can incite severe opposition. The opposite, a well-defined regime, can induce action by decision-makers, improve public support and acceptance.
iii. The public policy institutional path can positively impact scale-up gains of maturing technologies;

iv. The risk perception regarding CO_2 storage is crucial for the social acceptance of the technology by the local communities;

v. The centralized governance can accelerate the development of industrial clusters. In such case, the rigid top-down coordination can reduce costs but increases the risks of failure of new technologies;

vi. Different business arrangements can reduce the CCS risks since they have been well-coordinated and costs and benefits ratio have been properly distributed;

vii. The unpredictable costs of long-term uncertainties may difficult the public authorities' decisions about the CCS and its role in mitigating climate change vis-a-vis other options such as clean energy generation.

viii. The long-term planning properly done by public sector or private agents collectively acting may represent a mechanism for reducing cost of carbon hubs.

3.6 CHAPTER 4 REFERENCES

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4. COSTS AND BENEFITS IN THE CLIMATE CHANGE PUBLIC POLICIES: THE BARRIERS TO THE CCS ACTIVITY AND THE GOVERNMENT'S ROLE OF RECONCILING PREFERENCES

4.1 INTRODUCTION

The transposition of international agreements into national market regulations, public policies, and the behaviour' changes of citizens' consumers represents a highly complex challenge for the various global climate change stakeholders and agents involved (Blum and Lövbrand, 2019; Nagy, 1994).

Between the economic world-leading governments and the business groups responsible for conducting cross-border trading operations, there is a labyrinthine institutional net for the cost's allocation through the production and distribution chains, which may result in deleterious effect of GHG emissions from its business' facilities unless appropriate incentives are put in place (Cooper, 2018; Fan and Friedmann, 2021).

The process of building institutional models that consider the real CO_2-GHG drivers have been a challenging task, mainly due to the high number of emitting agents along the production-consumption chain, and the capability to shadow its climate responsibilities, such as multiple interests on oil exportation, refining, transport, retailed system.

This shield arrangement occurs in the fossil fuels market and the distribution of climate costs along upward agents, in the energy market using preferential demand arrangement, in the fertilizer facilities, petrochemical and steel mills supplying globally smaller consumers who could not consider themselves important contributors to GHG increasing.

In this concept, the market failures may induce the gains in the production-consumption chain's upstream, however, keeping them ineligible for guilty conscience from consumers side or being incapable for shape participant's behaviour, and affecting the regulation to outline arrangements that transposes present high costs for future generation due to the complexity of their allocation (Araujo *et al.*, 2018). Therefore, the emerging position needed for a designated authority to deal with rebalancing climate change requirements empowers governmental regulatory role as an anchor for Greenhouse Gas Removal (GGR) implementing policy process.

This chapter aims to analyse the costs and benefits of the GHG chain related to CCS technology, the economic benefits in the production side to de diffused losses for consumers and the natural arbitration role for government and its regulatory instruments. In addition, it aims to point out the CCS technology as part of the climate change solution in the institutional assessment.

4.2 CONCENTRATED BENEFITS: THE RESPONSIVENESS TO ECONOMIC INCENTIVES

The climate change challenge agenda emerged through international agreements, and it has been discussed in the annual COP by the key GHG emitters countries. Although they have been committed to it, the system to transpose the agreements to the behaviours change has been complex and hard to implement.

The GHG emission facilities cannot be compared directly due to the costs, the projects' maturation, the resource needed to change the business-as-usual path, and the institutional frameworks consolidated and accepted by the key agents. The issue has been latent in the hard-to-abate industries, in which current business and the new low carbon economy represent Sophie's choice and the problem of the need to retrofit or decommission the facilities in the mature industrial cluster (IEA, 2019).

In this context, the energy and industrial large-scale stationary sources have presented a predisposition to concentrate the income, production and the capacity of added value from raw inputs under the regional monopolies or oligopolies systems, by cause of by the scale's economies, the natural monopolies, or the market failures innate to the infrastructure sectors considering its manufacturing chains.

In addition, in relation to the GHG life cycle, it prevails the income concentration in the upward production chain, in which it becomes inclined to cover up its carbon footprint forward, in later stages or at the end of the chain, favouring the consumption of the high carbon footprint goods due to its lower price in the business-as-usual path, and the complexity of competitively offering substitute goods in scale (Du *et al.*, 2020; Marz and Pfeiffer, 2020; Spiller, 2013).

In this analysis, fewer reallocational concepts have to be considered. The first is the convention of the stationary source into a stage of the production chain that obeys rational terms for the economy and the group's behaviour, having the CO_2-GHG emitters appearing as a consequence of rational incentives from the institutional framework. The large-scale facilities under market failures may obey long-term incomes and react to new institutions that threats to their dominance positions (Marz and Pfeiffer, 2020).

The second refers to the interconnection between the consumer market and the carbon footprint per product at the end of the chain and whose result is influenced by exogenous variables outside the productive chain. Fewer studies indicates final consumers are inclined to have green footprint and react against polluted stamps on products (Batalla-Bejerano *et al.*, 2020; Tobler *et al.*, 2012).

Moreover, the consumer's choice at the end of the chain is compelled to maintain an undesirable behaviour pattern, unless the previous incentives they were submitted justified opt to substitute goods, considering not only environmental patterns, but direct costs (Baldwin *et al.*, 2018; Galarraga *et al.*, 2020; Yu, 2012).

These structures, hegemonically, are pendent to the concentration of net revenues in the chain's ties where it is possible to combine synergies and organizational capacity to dispute the decision arenas subtly, and the effects do occur smoothly to the other agents' eyes, which makes them low have reduced capability to react and stay in the critical pole for public choice, even though they may represent the majority.

The organizations' and social groups' theory can contribute to understanding the case as mentioned above.

The starting point could be the studies carried out in the first half of the 20th century, which sought after understanding the organization of pressure (interest) groups intertwined with political groups and its symbiotic evolution (Bentley, 1908; Truman, 1951; Yoho, 1998).

In the interest groups, the search for the interests' defence of the legal and formal institution through informal activities arise by creating party platforms support ideas and causes that allow their leaders to influence public opinion and, consequently, to promote efficient advocacy in the public agenda. Even if they assumed different patterns and purpose, implicitly increasing their objective marginal utility, they failed to reduce the complexity of political and collective action from formal groups (Bentley, 1908).

Later, the concept was expanded to encompass potential groups and overlapping interests among them, the rules of play and the procedure to be followed in the society, and the latent purpose of obtaining favourable decisions toward other government groups, as well as understanding the pros and cons of achieving them (Bobbio *et al.*, 2004; Truman, 1951).

Regarding the organization of groups, as they are a characteristic of each society, the more complex and interdependent it is, the greater the group's importance, even within a stable, formal system and rigid political institutions, or into a highly complex society.

Then, the frequency and pattern of social relations among agents that make up the groups became relevant and changed over time. Thus, the previous patterns and habits (which is also considered a social institution) influence the actions and the behaviour of the members of a given group, and the frequency and persistence of this interaction may determine their potential influence (Truman, 1951).

The interest groups, on the other hand, are based on the sharing of attitudes and aim to plead with others for the establishment, maintenance, or improvement of behaviours binding to the position shared by them, and that present the associations as a necessary form of materialization of these species of groups, such as unions, employers' associations, trade and industry sectors (Truman, 1951).

As a counterpoint, the logic of action appears as a theory that the behaviour of individual groups, based on the rational choice of its components, will tend to the inertia regarding their interests unless there are the coercions' mechanisms or incentives that induce them to pay their costs involved in the common goals' pursuit when they involve public goods (Olson, 1965).

The provision of goods qualified as indivisible and non-excludable consumption, of difficult cost individualization, and avoid being part of the group responsible for bearing the costs of a given public good, the market failure of free-rider behaviour arises. Its effects increased under certain conditions outside John Nash's game theory (Sandler *et al.*, 1987).

The size of the group is considered an essential factor in defining the behaviour of its members (Olson, 1965).

In large groups, three factors may hinder the promotion of the goals to which they are dedicated. The first is about the larger the group is, the smaller benefit's share, the reward for collective joint action, and the possibility of achieving the optimal benefit each member takes. As a derivation of the first factor, the less likely a subgroup will obtain sufficient gain for it to pursue the collective benefit on its own. Then, the organizational complexity grows proportionally to the number of members, which ultimately makes consensus challenging to achieve (Olson, 1965).

Therefore, costs and benefits tend to be diluted among members, and, in contrast, the small groups have high unit costs, but they are driven by the specific benefit obtained by each party.

Within the group, the preference of part of the members to obtain a particular objective may be greater than that of the others (intensity), and thus they will be susceptible to incurring high costs to achieve this success. These members are qualified as privileged due to their ability to induce the behaviour's change of other players in favour of the group they belong to (Olson, 1965).

Olson also defines the exclusive (market) groups as the existence of entry barriers for new members since it would increase the cost of providing the benefit given to these affiliates, opposing the inclusive groups. Specific inclusive groups or imperfect market groups tend to be composed of members who consider the effects of their actions on other agents in the form of strategic interaction in which there is relevant mutual dependence inversely proportional to its size.

Regarding the group’s size, Olson (1965) suggests that it cannot be so small that a unique agent can acquire a collective benefit through individual action, even though the collective inertia can cause it, such as the case of industrial oligopolies, illustrated below.

In the CCS Business, this group´s size may help in the hidden mechanism of carbon footprint from selected industries to the rest of the society. Once the conglomerate corresponds other than first regional producers or global suppliers, they could become hidden by the diffused consumers, and, by inference, they are benefited by inertial positions while majors do not assume carbon costs. Thus, unless new mechanisms are established to change the inertial behaviour, non-major oil companies, regional electricity generators, N-Fertilizers or petrochemicals have been capable to postpone its present costs in terms of carbon emissions and they have not been sufficiently stimulated to deploy their CCS systems.

4.2.1 Where it can be observed in the CO_2-GHG emitting industry?

From the perspective of the industrial, some productive chains and its life cycle present particular bottlenecks or ties that may induce oligopsony or oligopoly behaviour. Considering the Olsonian theory, we suggest it could result the exclusive clubs’ formation, in which few individuals may have acted as an incentive to the singular past patterns of inertia comparing to the whole consumption system and whose behaviour before and after a turning point decision that change how they act, such as international climate change commitment after a mature economic structure based on fossil fuels.

In the past, at the first moment, there was not rules to impede an unpredictable and undesirable actions by the agents. For instance, when oil industry emerged, the general conditions did not tighten private agents that abused on its market advantages, and, in a few economic cycles, the public sector (governments) became more inclined to intervene and then avoid classic market failures (Yergin, 2012).

In the climate change, other variables that shaped CO_2-GHG emissions' conditions established a form of benefit through the emissions charges exemption of which added to the previous institutions, drove the infrastructure deployment based on high GHG emission levels by fossil fuel chain. For them, the incomes are inclined to concentrate in the first stages of the production chain as a benefit, from the consumers to the oil producers, having a market concentration and verticalization regardless the business size (Marz and Pfeiffer, 2020; Pecorino, 2001; Pitelis and Tomlinson, 2017; Spiller, 2013).

The transactional costs in these sectors represent a strong vector for managing incentives and economic driver policies faced the sunk cost of capital, the commodities' cyclicality risks, and, the difficult to change the economic trajectory significantly when after achieves maturity due to the lock-in process (Fouquet, 2016; Howlett and Rayner, 2007; Spiller, 2013).

The fossil fuels-based electricity occurs downstream the petroleum industry in the consumer side, and their stationary sources figures as leading GHG polluters considering life cycle perspective. From infrastructure analysis, the operational mechanism for converting products to the final tie, the electric energy, is to be used in other production stages, but especially by the final consumer (Zweifel *et al.*, 2017).

The nitrogen ammonia fertilizer industry is generally based on Haber-Bosch process, combining nitrogen from air with hydrogen produced by methane. The costs of producing nitrogen fertilizers is based on natural gas as raw material for hydrogen production via steam methane reforming (SMR), and, despite the steam process being used in the industry than ammonia production, the need of hydrogen and its energy demand represent the crucial vector to the final cost of N-fertilizer to the agriculture (Hasler *et al.*, 2017; Hoffman *et al.*, 2018). The result is approximately one tonne of ammonia for each tonne of pure carbon dioxide as low hanging fruit.

Thus, due to its dependency of hydrocarbon as raw material, N-Fertilizers can figures vulnerable for commodities prices oscillation, verticalization process, or transactional costs that barrier the risks of cyclic prices, such as the preferential choice of natural gas instead of coal for nitrogen fertilizer production plants in terms of regional markets, and whose firm consumption characteristic was a necessary condition to make fewer gas fields feasible (Parikh *et al.*, 2009; Quader, 2003).

The position of N-fertilizer facilities increases risks due to the share of the total cost and the possibility of being under an oligopoly market failure by purchasing natural gas. The fertilizer facilities have been input price dependent, have a complex logistic chain of the reduced ratio of price per tonne of product, which allows substantial gains for verticalized conglomerates that can jointly supply the adjacent sectors, also concentrated, in which the cost factor discourage the new agents' entry (al Rawashdeh and Maxwell, 2014; Wilson *et al.*, 2015).

The arrangement may infers that there is either relevant market power, as a buyer of those commodities, or stimulus for verticalization with the previous stages, considering the approach of the business and industrial sectors via corporate organizations and various contracts, but maintain adverse effects for the other agents outside the Oligopsonistic-oligopolistic flow (Ferrer, 2013).

By configuring itself as a reduced members group, having defined and cohesive objectives, and having market power towards to influence the high number of consumers dependent on that, it induces the concentration of benefits.

In terms of collective gains, the organization into global groups allows for concentration of gains for oligopolistic members, with few privileged or latent interest members, and the high cost of entry of new members.

The steel and petrochemical industries can adapt to different input supply conditions, but they depend on competitiveness via costs' control and access to consumer markets (Lawal *et al.*, 2021). The need for a preeminent amount of capital for a new agent to enter the market and the competition with global agents concedes benefits to maintain the activity in specific countries a key factor. Thus, the industrial groups involved adapt to the conditions they are submitted, but with immediate consequences when the other agents (consumers, governments, or suppliers) fail to offer benefits, regardless of how this gain is configured (Fan and Friedmann, 2021).

Stakeholders may seek to organize themselves to reduce long-term risks, even if the immediate results are costly as a way of adapting to economic and environmental conditions (responsiveness).

A possible regional solution is the vertical integration, which is observed in the incorporation or acquisition of hydrocarbon exploration and production assets by companies focused on refining, natural gas, and global marketing of these commodities, and, in addition, these groups can obtain participation in oligopsonistic sectors such as petrochemicals, fertilizers, and electricity, making them have bargaining power in the acquisition of energy inputs (Andersen and Gulbrandsen, 2020; Lawal *et al.*, 2021).

Alternatively, it is possible to increase international trade based on carbon markets and attract new private investments that may affect the regional, reducing the oligopolies and oligopsonies. The likely consequence is that once global business grows, the market may induce a new concentration via merge and acquisition (M&A) in the long term.

The horizontal integration can also apply, through the acquisition of regional competitors, seeking to increase market power and influence the price of other agents(Williamson, 1975).

Finally, there is the latent defence of interests with the government, which materializes via exemptions, subsidies, public funding, or various market restriction mechanisms. In short, these are ways of concentrating benefits in the ties in which a bottleneck appears in the production flow and whose adaptive capacity is proportionally linked to the bargaining power vis-à-vis other agents, including the same interest group.

4.3 DIFFUSE EFFECTS ON SOCIETY AND THE DIFFICULTY OF RESPONDING ON THE DEMAND SIDE

The assessment of consumer preferences has been the subject of analysis to improve legal and institutional models applied to climate change. As the final link in the life cycle involving CO_2-GHG emissions, consumers are dependent on choices and patterns pre-determined via interactions of sectoral regulation, economic factors, availability of primary energy sources, as well as the ability to convert them into goods and services to be consumed according to the conceptions of cost, sustainable consumption, propensity to commit to the collective purpose, among several factors whose weight will vary according to the region under analysis (Batalla-Bejerano *et al.*, 2020; Hall *et al.*, 2020; Tobler *et al.*, 2012; Yu, 2012).

For this purpose, the starting point is assumed to be the rigidity of obtaining a spare response from the demand, its behaviour as a consumer, and the preferences regarding the goods affected by direct climate change, such as energy inputs, and indirect, such as goods derived from petrochemicals, fertilizers, and cement. Although the same individual is included in a myriad of sectors, the behaviour observed will diverge in terms of preferences for greater or lesser adherence to the environmental cause.

Under certain conditions, consumers may present a consumption profile aligned to the emission reduction targets, but the association is difficult to be done directly. The theme of sustainability has been a part of the school curriculum to raise awareness of future generations. However, the primary correlation with the habits of the end-user remains the effects on the cost of acquisition of goods, and that, without guarantees that the benefits outweigh the costs in the long term, it would tend to the permanence of past habit (Gadenne *et al.*, 2011). However, that would not appear as an obstacle to partial support for expanding renewable electricity generation, such as through wind power (Thøgersen and Noblet, 2012).

In addition, under the final consumers, the purchase of energy-efficient goods appears. The choice between a more efficient or expensive vehicle, or even a fuel-efficient car and a cheaper vehicle can be influenced by the availability of information and the establishment of labelling standards easily recognized by end-users, and by the possibility of external influence via public leadership (Galarraga *et al.*, 2020).

Nevertheless, the choice between efficiency and price can mask how consumers pick their goods up in the arrangement already established by key players in the industry, even considering the possible answer to carbon footprint labelling schemes, vehicles choices, or the effects of enclosure, exclusion, entrenchment and encroachment linked to climate mitigation efforts (Galarraga *et al.*, 2020; Sovacool, 2021).

Therefore, the consumer is a participant in, but dependent on, the downstream choices made by the other agents involved, and, if they are under faulty coordination, the cost of efficient choice by the consumer marginally alters life-cycle emissions.

A recent study based on scenario modelling indicated that final consumers, as decision-makers affecting them, show a preference for established or mature technologies in the free-market theory (Knobloch *et al.*, 2019).. This behaviour is linked to the loss aversion studied through prospect theory (Knobloch *et al.*, 2019). Consequently, the choice for electric vehicles should be preceded by recognizing the technology as being mature to the point of mitigating the risk aversion.

The combination of distributed generation and intelligent electricity grids is one of the most prominent cases of the consumer's role as an agent responsible for reducing emissions. The consumer-generator of electricity has been encouraged to produce electricity through sources that do not emit GHGs and has become the subject of constant evaluation for better understanding the relationship between consumption and environmental factors. It has been a major player in the new energy markets.

First, it increased the need for public financial support for residential consumers to cover the costs of distributed generation projects, awareness campaigns, and strengthening confidence in the new system (Gangale *et al.*, 2013). Subsequently, it was observed that the economic benefit factor was necessary for shaping the habits of these consumers, and a diversity of socioeconomic, cultural, and generational factors influenced consumers' behaviour (Batalla-Bejerano *et al.*, 2020).

Thus, we might infer that the final consumer, as a responsible demand-side agent, can be influenced by public leaderships, support renewable sources and mitigation actions for CO_2-GHG emissions, and he can make better decisions as reliable information standards are available and incorporated into everyday life. However, the consumption's decision depends on the cost of the infrastructure (product) and the need for confidence in the technology used (maturity) against risk aversion and perception of economic benefit to be obtained. By deducing, nowadays, most consumers are not aware of emerging technologies despite the latent and possible opposition to the CCS technology due to its immaturity under consumer´s eyes until public perception turn around to a more comfortable thinking about its business (Moon *et al.*, 2020).

The exception would be the distributed generation technology, in which the consumer has been able to respond effectively on the demand side, establishing a hedge against the electricity price' oscillations and, them, leading to a GGR pattern given the predominant solar as energy source. To the second matter, the electrification of transport sector also appears as potential consumers choice, but they also do not fulfil the net-zero emissions standard desirable.

Even having such improvements in the consumption behaviour, CO_2-GHG emissions remained significantly high due to other sectors. Considering that a potential consumer decides to adhere to the well-known low carbon economy's solutions, it may have the behaving sustainably perception, despite the fact that it would be impracticable due to other individual decisions considering the diffusion of responsibility to collective behaviour.

This pattern implies, in our thought, inaction by the consumer in the presence of their peers, i.e., as part of a group, the consumer will not adopt a different behaviour from the others (inertia) because he believes that he will not be held accountable (difficulty of accountability) for his inaction, added to the generalized behaviour. Possible causes have been the anonymity, which does not allow the individualization of the cost or obligation; the hierarchical position in which the consumer is, at the end of the production chain; the lack of expertise to solve the problem; and the size of the group involved, which is opposite to that observed in the production as mentioned above oligopolies.

In sum, there are occasional actions in which a positive result is found on the consumer's side. In general, pointing the GHG emissions at the end of the chain does not bring to the final agent identity as an individual affected by his actions through space and time; thus, those agents that cause environmental damage, which is diffuse in the production and consumption chain, do not feel encouraged to change their previous and inertial behaviour in the absence of external factors. Nevertheless, these patterns may change over time, particularly due to the influence of the new generation by voting, which includes their perceptions of the climate emergency, and due to the media power in the internet era.

4.4 THE GOVERNMENT AND ITS ROLE IN ARBITRATING INTERESTS

In the case of having a coercive force or an independent external incentive for intermediate-sized or latent groups, then the expected behaviour could be achieved by the group target of the public action (Olson, 1965).

It means the probability of a small coeval group organize itself under the collective action umbrella and obtain benefits to the detriment of many diffuse agents, which allows them to adopt a free-rider pattern when an agent or a group manages to receive an extra benefit than what would be expected to it, or the rent-seeking behaviour when the increase of the agents' income result from the reduction of the benefits of other agents instead of being linked to its productivity (Pecorino, 2001). For that, both market failures are typically observed in the climate change agenda, especially evolving private sector, SOE, or State-Controlled Enterprise, when they tend to achieve fiscal benefits to have the cost shared for diffused costumers.

Consequently, it competes to states or governmental agents to receive the needs from the myriad of interest groups, arbitrate, negotiate and ponder to materialize them on public policies, feedbacking and remodelling themselves whenever desirable, taking into account the complexity resulted from global phenomena, political coalitions, and the limitations of the state intervention tools, regarding the State relative autonomy (Souza, 2006).

This task is paramount for the climate change agenda due to its results through collective action and the potential damage due to the absence of adequate state empowerment and capability to act. Then, the acquiescence of the state intermediation, a dysfunction in the group thinking, can emerge from the consensus search among the opinion variation and its groups demanding the same governmental action without crossing interests.

Each group may seek to increase its marginal utility, regardless of the Pareto-efficiency dilemma. In the typical case, the absence of leadership among the groups can drive key triggers that obtain undesirable caused of the false consensus. The agent from a group may tend to make less effort when cooperating than individually when he needs to face collectively with a defined problem. This behaviour may have been interpreted through the diffused responsibility paradox in which personal duties differ from the sum of collective responsibilities since group members may opt for inertial behaviour or even may spend less than necessary. It then will not assimilate the collective responsibility desired (risk-taking behaviour). In this manner, governments must play a leadership role to avoid false consensus, delegate competencies, and formulate and implement public policies convergent to the purpose for which they are intended (Souza, 2006).

Several researchers aimed to understand the conversion of group demands into government action, as followed.

The bounded rational driver model proposed that decision-makers were not able to adopt the best result formula due to the information asymmetry between private agents and governments, from regulatory agents and its market regulated agents, between temporal and non-temporal issues, and the convergent or diffuse interests, including those of decision-makers, which could be mitigated through the establishment of boundary conditions that framed the actors towards the desired path (Lubashevsky *et al.*, 2008; Simon, 1957).

Afterward, the exogenous factors have been integrated into the model, and the impossibility of blocking the decision process could be revised posteriori (Lindblom and Lindblom, 1959).

The development of the incremental view tried to encompass the behaviour in which the decision-making process was done only incrementally by the margin and supported by the bureaucracy's observations responsible for the public budgets. This factor induces minor changes by governments in the future due to the past decisions path, then getting it challenging to change course (Lindblom, 1979; Souza, 2006), as well as the difficulties of incorporating new technologies in sectors where there is a problem of high dependence on past choices (Fouquet, 2016).

A prominent study refers to the public policy as an outcome of politics, of an expectation from interpersonal relationships and the plurality surrounding it, and the supports and obstacles in the various debate arenas, which allowed subdivided into four public policies categories (Lowi, 1972):

i. The constitutive policy, which corresponds to establishing the rules of the game and the competencies of each agent;
ii. The regulatory policy, which aims to mold behaviours and conducts economic sectors, from the beginning of the production chain, from foreign trade to the final consumer, a priori, permeable to plurality proportional to the correlation of forces;
iii. The distributive policy that results in the granting of concentrated benefits to a few groups and the distribution of costs in a diffuse manner; and
iv. The redistributive policy linked to the benefits' concentration for a group and also the costs concentration in several agents.

Moreover, the possible interchangeability of a given policy is neglected, which means it fits into multiple categories, then qualifying the government action as regulatory and distributive at the same time (Secchi, 2012). Therefore, the public policy typology has been refined by correlating public policy and political interconnections, focusing on the concentrated or diffuse costs and benefits, from clientelist to entrepreneurial policy (Wilson, 1992).

The public authorities have two distinct roles to play. The first is the internal function regarding the climate change agenda. Government mediates interests between oligopolistic agents, who tend to concentrate benefits on its side, and the consumers, who are poorly organized and destitute of relevant bargaining power, which reduces its influence power to shape other agents' behavior.

In the comprehensive approach, the State's production assets' organization implies the producers' behaviour enhancements once they calculate the risk returns in the present position and how it affects long-term benefit, even though it causes a patronized action of the agents.

After establishing the game rules, the introduction of multiple and complex elements facing the externalities and its non-estimated prices, such as energy justice in the low carbon economy or sustainable development patterns, imply an agreement's renegotiation between the government and agents that will perform incrementally from small changes in the benefit-cost flow, considering the lack of disruptive innovations.

Despite this, new modular governance arrangements have been analysed to mitigate complex sustainability transition processes and adopt intelligent trial-and-error algorithms and realistic targets to accelerate change via incremental processes (Low *et al.*, 2012; Manning and Reinecke, 2016). Even in the arbitration position for the government, the use of tax policies or cap-and-trade rules remained a tool for carbon pricing and consumers' knowledge (Hsu *et al.*, 2017).

The second role refers to the international relations between countries to solve common problems between peers when pricing complexity. Within this framework, in the first role, the State proposed the legal and regulatory frameworks for climate change public policies using the vertical interrelationship, a top-down policy. Au contraire, in the second role, the negotiation under the dialogue among peers the negotiation follows the horizontal and reciprocal relationship, avoiding the precise impositions by dominant agents, however, using diplomacy and foreign trade bargaining power. Thus, international agreements are negotiated with extreme caution, considering the impact by incorporating new obligations into a miscellaneous economic sector, compromising internal public policies, and unbalancing interest groups already positioned. For instance, the proposal to adopt ethanol as a substitute for fossil fuels in the Otto-cycle engines, whose favourable geographic region for sugarcane and corn ethanol, makes biofuels produced in Brazil and USA competitive and hindered the oil industry' interests from mature countries (Mathews, 2007).

In summary, the State has the competence to establish game rules to avoid rent-seeking behaviour or free rider in the short term when it occurs regardless of the broader interest of the society, including climate change concerns; and use its empowerment by law to keep the long-term path for a low carbon economy. In addition, the multiple interests and groups need to be attentively observed when acting in the domestic and foreign policy arenas, under the risk of compromising main goals, such as the climate change challenge and the technologies achieve them. The table 1 below summarize the relationship between CCS related business chain and consumers, and the governments' roles.

Table 4.1. *Predictable agents' behaviour in the CCS related business chains.*

Agent´s group	Behaviours	Costs	Benefits
CO_2-GHG emitters industries	Oligopolistic and Oligopsonistic Rent-seeking Incentive responsiveness Marginal utility driven Verticalization Barriers claimant Carbon leakage and free rider	Lock-in in the business-as-usual Resistance to disruptive changes High costs for the collectiveness and for final uses Industries' lock-in	Capable to influence governments High long-term internal rate of return (IRR) Avoid new competitors due to the barriers to entry
Consumers	Low capacity to self-organization Diffused costs Environment and cost driven Inertial consumer habit Short-term financial response Bottle-up policy	Uncapable to drive major changes Avoid new technologies Weak Accountability	Major decisions are put in place by implicit delegation Their needs are neglected by decision-makers Disruptive technologies
Governments	Hierarchical coordination Interventions in the market failures Arbitration Implement major rules Political decision driven Redistributive Peers' negotiation Top-down policy	Free rider Asymmetric information Soft power inclination Technocracy capture Unpredictable costs' transferring for consumers Lock-in policies	Picking winners policy Top-down decisions Regulation Improve benefits outreach Allocate cost through business chain

4.5 FINAL REMARKS

Concerning on upstream side in the GHG industry, entrepreneur groups that controls manufacturing production have been capable of composing small groups, economically relevant and well organized in terms of interests, and influencing hosted states to obtain benefits or avoid high costs. On the other side, consumers, in general, tend to be sub represented in the political arena; then, they do not have control to drive long-term interest of the whole society.

It may happen due to the complexity to deal with interrelated sectors, mixing strongly regulated, such as electricity, with more market priced, as steel, fertilizers and petrochemicals.

This situation may cause an unintended inertia in the production-consumer chain maintain the short-term cost method, and the major climate change solution could be neglected as long as its institutional patterns continue being supported.

For that, through regulatory patterns and institutional changes for the new path, the mechanism of governmental arbitration and intervention can improve CCS technology into the climate change agenda. Building regulation and economic incentives that adequate long-term costs, risks, and revenues along the chain could incrementally enhance the existing regional arrangements or the multi-countries approach to the business climate issues.

Moreover, in sectors where capture costs discourage the agents from investing, the role of R&D is crucial to scale up the learning curve effects and then deploy the chain downstream. This is more evident considering that the current institutions maintain hidden subsidies for fossil fuels that work against the need for significant investments for scaling up the carbon hubs.

The challenge to change the path dependence of the business-as-usual, that maintain unsuitable environmental patterns, and incentivize the mix of new low carbon technologies, including the CCS activities in the climate change agenda, will demand synchronism and a multiple synergy among those who have to pay for goods, who take advantage to increase profits, and the governments to negotiate with each other, and into their jurisdictions.

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5. INSTITUTIONAL, LEGAL AND REGULATORY FRAMEWORK FOR CCS: HOW TO LEARN WITH PREVIOUS EXPERIENCES

5.1 INTRODUCTION

Building game rules for CCS activities can be considered crucial in developing the new carbon business based on geological sequestration and its application to climate mitigation policies. Early efforts sought to enhance understanding the existing legislation in those sectors, which have played an essential role as GHG emitters or the potential agent in the CCS chain, taking into account other low-carbon policies, economic competitiveness, employment, and energy security (IEA, 2010).

The legal barriers and gaps were, as a rule, contained in some CCS critical issues well known by society. However, some issues seemed more important than others during the CCS development over the last decade. As minimum mechanisms for the viability of large-scale projects with lower total cost, they involve: incentives for CCS within the climate change mitigation strategy, the role of environmental assessment, the techno-economy of capture, permitting process for permanent storage, the long-term liability, and the BECCS in the net-zero emission target (José Ricardo Lemes de Almeida *et al.*, 2017; Daggash *et al.*, 2020; Herzog, 2017; IEA, 2010; IPCC, 2006; Khan *et al.*, 2016)

After the CCS nascent period in the legal and regulatory area, a set of frameworks was developed in the most heterogeneous forms and institutions. According to the level of change in the institutions in force in each country, they were segmented into five broad groups of legislation, which, a priori, were necessary to make CCS activity feasible. (Havercroft and Macrory, 2018).

Therefore, this paper aims to analyse the regulatory and institutional frameworks provided by key CCS implementing countries, considering how they succeeded, how they failed, and to establish which mechanisms were more critical for reaching CCS businesses, highlighting the competent authorities and relevant incentive institutes.

5.2 METHOD AND PROCEDURE

The hypothesis suggests that international experience could provide a comprehensive set of legal, regulatory, and institutional arrangements and actions to stimulate the CCS large-scale development in potential countries. It considers the legal framework can reduce uncertainties for the agents involved; however, it is not enough to scale up CCS activities, which infer that it has incentives out of its CCS legal frameworks allowing economic profits under CCS projects, directly or indirectly, via other factors into institutional arrangement surrounding the boundary where the project is commercially operating.

One of the most well-known tools for assessing the CCS framework is analysing the legal systems established and how they have been built. Those models have been firstly classified in a comprehensive view.

The first group, more comprehensive, shapes CCS within the general legal framework application, while, in the second group, the legal framework applies to a specific project. The third refers to the oil and gas regulatory and legal frameworks adaptation via amendment process, and the fourth is characterized by an autonomous regime resulting from adaptations in more than one legal regime. The fifth model occurs when the environmental legal framework is changed enough to allow the adjunct development of the CCS legal regime (Havercroft and Macrory, 2018).

However, those researches fail as regards the role of government actions through public enterprise. For that, a sixth model, barely described in the literature, occurs when there is an absence or a partial gap of the CCS legal framework or when the agent responsible for CCS implementation is hidden, which constitutes a barrier to the effective development of the CCS business. This occurs when, despite the gap, the agent decides to implement a CCS project effectively, whether for institutional reasons outside the legal business institution or due to political decisions from the Executive Branch to its State-Owned Enterprise (SOE).

From the former experiences, some results can help understand the paths of greater acceptance and less resistance to the success of CCS in a low carbon economy scenario.

Countries have been elected on the following criteria:

a. having expertise in the CCS large-scale business;
b. public engagement with the climate change agenda and hard-to-abate sectors; and
c. providing arrangements favourable for CCS large-scale project and applicable to other countries, such as using SOE, subnational framework for CCS development, or an innovative mechanism for long-term liability problems.

A significant advantage of the method is covering a representative group of policies to be adopted considering countries' peculiarities. The second benefit is using previous experience, avoiding major fails in the learning by doing implementing policies.

Later, a few countries were removed due to the lack of literature available; the deficient information could compromise the analysis. We selected nine countries: Australia, European Union (United Kingdom, Norway, and the Netherlands), the USA and Canada. In addition, China, the United Emirates, and Saudi Arabia were included due to their potential engagement with the CCS business via their governments.

In particular, the analyses performed were based on the literature and research papers found by using keywords, such as “CCS”, “CCUS”, “economic assessment”, “institutional assessment”, “legal framework”, and “CCS deployment” in the online platforms Web of Science, Google Academics, and Science Direct. These analyses could be biased since the literature available overvalues the oil sector experience. Further research would be necessary to better understand the CCS industry in other GHG high emitting countries, such as Japan and India, and significant fossil fuel producers.

They could be biased from past extensive literature available and tends to merge itself with the oil sector’s experience. Further research would be necessary to understand better the CCS industry in other GHG high emitters countries, such as Japan and India, and significant fossil fuel producers.

Therefore, the critical question is understanding how GHG emitting countries implemented the CCS large-scale projects.

5.3 AUSTRALIA

The Greenhouse Gas Reduction (GGR) policies implemented by natural resource-dependent countries (such as Australia) need to consider exogenous effects other than climate change. Australia fits into two key segments of the GHG mining industry, and CCUS seems to figure as a key to advocating its interests before other countries.

Concerning climate agreement, Australia has been engaged since the Kyoto Protocol, in 1997, although the ratification process was completed only a decade later, when the cap GHG emission target of 108% was established, based on the 1990 level, achieving 591.5 Mt/CO_2 per year. Later, in 2015, they endorsed the second commitment period, covering from 2013 to 2020, having 99.5% of 1990 as the cap target. By the Paris Agreement NDC, the government tried to compute virtual carbon dioxide surplus abatement at the Kyoto Protocol target as a credit to the COP-21 goal.[5,6].

The process of defining an internal consensus on the Kyoto Protocol (or even any climate agreement) showed to be a sticking point for crucial parties. In 2002, the incumbent party was inclined to reject this agreement due to its alignment to the USA stance in the Bush administration and to potential economic losses (Howarth and Foxall, 2010). This political alignment had a slight difference about who will be responsible for GHG emission in the production-consumption chains. For the USA, the final consumer criteria imply high cost, whereas for Australia, distribution through the business chain tends to result in losses upstream.

Thus, by the current climate agreement decision process, political agendas have fluctuated between left and right wings as regards international climate issues, although economic agendas have constrained a real engagement with GGR (Howarth and Foxall, 2010).

The energy sector has been a bottleneck for the Australian low carbon economy. Fossil fuel represents 70% of its capacity, accounting for more than 80% of the total electricity demand due to energy security and economic feasibility parameters (B.P., 2019; IEA, 2018). A critical economic driver has been coal and natural gas (NG) in supply once it has a commodity exporter profile. Major coal and NG production supply the Asia-Pacific area, reaching almost half of its resource exports; thus, its economy has a carbon footprint lock-in hinge on its innate capabilities (Araujo & Costa, 2021; B.P., 2019; Cunningham *et al.*, 2019).

The Australian Commonwealth developed a comprehensive CCS legal system, involving federative subnational entities and federal government, in an attempt to use complementary competence to cover comprehensive needs (Dixon *et al.*, 2015; Gibbs, 2018). In its climate commitment, after 2007, the CCS legal frameworks

[5] Australian international trade is susceptible to green economy constraints due to the high concentration of coal, natural gas, and iron ore.
[6] https://www.theguardian.com/environment/2019/oct/22/australia-is-the-only-country-using-carryover-climate-credits-officials-admit. Access: 25 Mar. 2021.

emerged to input agreement stability under collaboration values in contrast to predatory behaviour.

The federal government is responsible for offshore activities superior to three nautical miles, and the main activity under its rules is hydrocarbon exploration. The Offshore Petroleum and Greenhouse Gas Storage Act 2006 was approved in 2006 as a regulatory framework mainly related to natural gas extraction.

In 2008, the Australian Parliament approved the Greenhouse Gas Storage act by amending the Offshore Petroleum legislation to enhance the framework regulating CCS, covering underground formations, facilities, licensing, permitting procedures, the competent authority on Commonwealth Minister's hierarchy, and the GHG general regime scope, followed by infralegal procedures and regulations[7], and the authority for safety and environmental issues under its jurisdiction (Araujo and Costa, 2021).

The first proposal advocated a possible new legal framework instead of an amendment to the petroleum legal framework. However, the Federal Parliament considered a system of rule as inefficient, in theory, decoupled of the oil sector considering that operators were most likely to develop CCS activities on offshore seas under Australian jurisdiction. Summarily, using synergies between CCS and the oil industry allows the Parliament to choose a third path to build a carbon sequestration regulatory framework, leaving long-term liability issues as a weak point (Gibbs, 2018; Havercroft and Macrory, 2018).

The second movement tried to deal with vital potential bottlenecks that could constrain the CCS nascent industry, which resulted in congressional discussion to approve an amendment that establishes rules for the Commonwealth government to assume operator costs for liabilities after a comparable assurance period, usually defined as fifteen years by the competent authority (Ekins *et al.*, 2017).

Several states have implemented a specific framework for CCS activities onshore and up to three nautical miles. Based on theory, they could presumptively

[7] For instance, the Offshore Petroleum and Greenhouse Gas Safety Regulation (2009), Injection and Storage, and Resource Management and Administration (2011), and pipeline standard.

apply a typical federal framework mirror, even because of needing to homogenize coincident rules.

For onshore CCS activities, Victoria State approved one of the first regulatory models, a stand-alone legal framework for onshore activities that differs for not accepting long-term liability transfer as the Commonwealth has done. Moreover, the Victorian Onshore Act that Minister can declare that no land or land class can be used for carbon dioxide sequestration to protect such land for significant environmental reasons, while activities in certain wildlands remain forbidden.

For waters under Victoria's jurisdiction, it is an offense to inject a substance into the seabed or subsoil of the offshore area or store a substance in such locations unless authorized under a greenhouse gas injection license or otherwise authorized under Act or other applicable law or regulation. Even using two models, Victoria's rules incorporated into its framework were quite close to the Offshore Petroleum Act 2006, at the federal level.

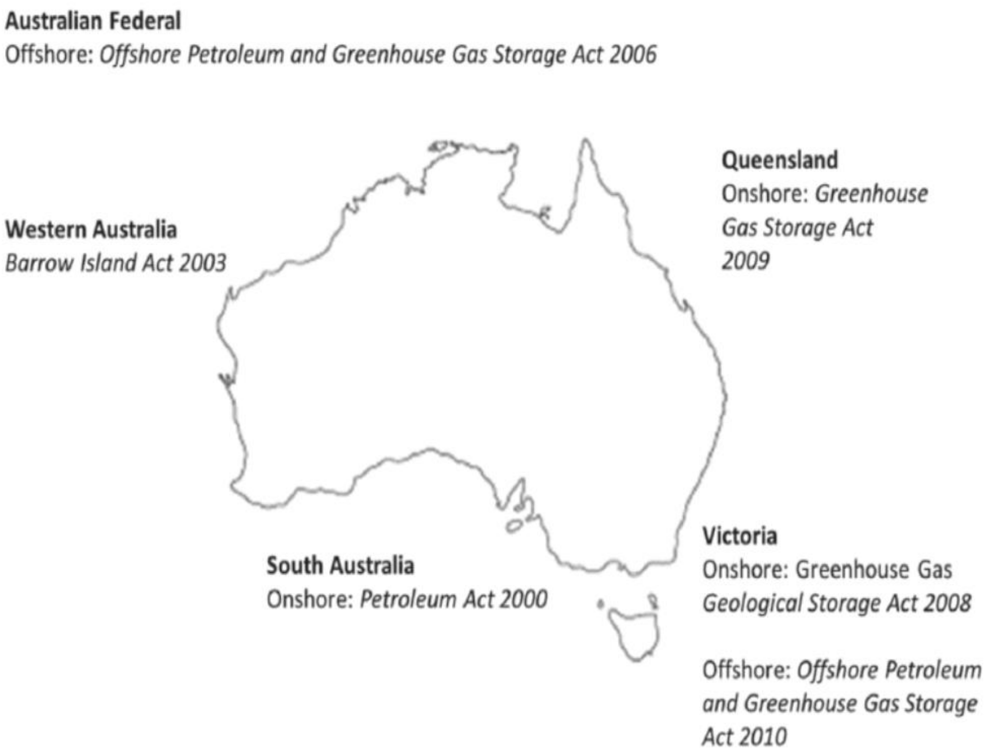
The Queensland State enacted the Gas Storage Act 2009, as a stand-alone legal framework in which the exploration permits and injection and storage leases for greenhouse gas storage activities cannot be granted or renewed until an environmental authority has been issued for all environmentally relevant activities proposed to be undertaken.

This Act predicts that applicants for exploration permits, and injection and storage leases must be concerned with potential water issues in developing work programs and development plans, and its documents cannot be accepted until they have been approved by the minister responsible for administering the Water Act; besides, leaseholders cannot take or interfere with water (as defined under the Water Act 2000) unless the taking or interference is authorized under that Act.

In South Australia, an enhanced path has been implemented by an amendment to the Petroleum and Geothermal Energy Act 2000 and its regulations to stipulate the competent authority on environmental issues as an entity that must be consulted before the project is approved. Also, in the legal system, the Minister and authorized officers have certain powers to conduct the license process, including directions to prevent or to minimize environmental damage and to rehabilitate polluted lands. Licensees are liable to compensate the State for costs of environmental rehabilitation that the public sector must carry out due to severe environmental damage or the threat or potential of severe environmental damage arising from activities carried out under a license.

According to Figure 1, legal systems have a double jurisdiction layer (State and Federal levels), through a myriad of models (Havercroft and Macrory, 2018), such as the stand-alone (Victoria and Queensland), the amendment to the petroleum framework (Federal level, Victoria's offshore and South Australia), and the tailor-made framework (Borrow Island), which cover the single current large-scale project in Australia. Note that the Australian model focuses on the storage phase rather than on CCS as a whole

Figure 5.1. *Carbon sequestration frameworks in the Australian territory.*



Source: Extracted from Gibbs (2018).

A most different and important state-run legislation was implemented in Western Australia (W.A.).

The Borrow Island Act, enacted in 2003[8], was approved to deal with only one project as a mechanism to ratify and to authorize an implementation agreement between the State and the Gorgon J.V. related to a proposal to undertake offshore production of natural gas and other petroleum and a gas processing and infrastructure project on Barrow Island. To homogenize long-term liability clauses, the W.A. Parliament made an amendment adjusting its framework to new terms corresponding to federal post-closure requirements[9], building a prominent world-class example of what government and industry could achieve to reduce carbon footprint, and deal with carbon dioxide in the Gorgon gas field[10].

The Gorgon project has its legal framework and, as a sui generis case, W.A. was responsible for covering one-fifth while the Commonwealth would be in charge for the remainder of occasional costs in terms of post-closure long-term liability, and both entities remained silent about ownership of the pore space (Swayne and Phillips, 2012).

5.4 THE ROLE OF CCS INTO EUROPEAN CLIMATE CHANGE POLICY

The European Union (EU) has been a critical pole to implement CCS as a whole.

The first step was having the EU Parliament approved a broad legal framework, the Council Directive 2009/31/EC, which handles public concerns of long-term safe CO_2 storage, and, in theory, whether interpreted together with the

[8] https://www.legislation.wa.gov.au/legislation/statutes.nsf/main_mrtitle_76_homepage.html. Access: 27 Mar. 2021.
[9] https://www.parliament.wa.gov.au/publications/tabledpapers.nsf/displaypaper/3912728a9d54fcf4c071806048257e0c003d6ddb/$file/2728.pdf. Access: 23 Sep. 2021.
[10] https://www.parliament.wa.gov.au/Parliament/Bills.nsf/9D4676B11F1471BC48257E0C001AA55F/$File/Bill87-1BSR.pdf. Access: 23 Sep. 2021.

environmental guiding principles, holds the whole CCS phases, from capture to long-standing monitoring process after the injection ends (Velkova, 2018).

The EU-CCS Directive[11] brings a purpose related to CO_2 safe geological storage, reducing the risk involved, and it represents a milestone for carbon sequestration in a permanent way and its climate change mitigation policies in Europe (Dixon *et al.*, 2015). It has provided mechanisms to ensure environmentally safe geological storage, rules for transporting, and site choice as adequate liabilities for damage to health and property. The outlook was, primarily, for gradual and continuous growth in activity throughout its implementation.

This directive targeted the provision of standard guidelines to deal with responsibility, risks, or even the management of geological traps as the natural resource to permanently store carbon dioxide, leaving essential conditions to be regulated under each Member Estate rules, which has been a bottleneck to be solved over the last decade (Reins, 2018).

In addition, when designing public policies, those countries could follow fewer recommendations, highlighting the needs for support by the public sector for developing and deploying the CCS industry by the least-cost portfolio; for the engagement of industries in the competitive CCS prospects, and improving the learning curve of the whole chain; for incentivizing the CCS clusters deployment in selected industries via cooperation based on shared infrastructure to reduce capture costs in its processes. (IEA, 2019, 2016, 2013, 2010).

The Member States should define complementary frameworks beyond the boundary conditions under the directive. From them, the first bottleneck was establishing permission for CO_2 storage sites in their territories.

Allowing the storage phase in a territory is not trivial due to the need for monitoring, facilities operation, managing risks for long periods and to the liabilities involved. This is the most enduring and uncertain phase of a large-scale CCS project,

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[11] Directive 2009/31/EC of the European Parliament, amended by the Council Directive 85/337/EEC, and the Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation nº 1013/2006. Available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0031. Access: 23 Sep. 2021.

once it takes decades for ceasing its effects on the business or the government burden, and risks tend to concentrate on the agent responsible for the final disposal. In addition, long-term liability clauses under the directive have suggested a minimum of 20 years post-closure injection by the operator to get the site back to national authority.

Another decisive subject is setting the concept of negligible leakage during a project life cycle, which is closely related to the operator's technical and financial capacities to funding business risks. Member states must ensure that the permitted geological site will be technically safe to trap the carbon dioxide injected, under the definition of what could be accepted as minor leakage, considering a possible interaction between previous fluids and embedding rock (Raza *et al.*, 2019; Velkova, 2018; Verma, 2015).

Moreover, European countries must assess the technical and economic feasibility for new combustion large-plants to enforce them to reserve the area for the equipment required for the capture phase, once it proves viable transport conditions from the retrofitted capture source to. Nevertheless, achieving those conditions has not been outspoken, then, countries assimilate it just as a guideline instead of structural conditions to new large plants (Velkova, 2018).

The European Commission (EC) was designated to manifest on CCS projects on implementing the early phase of the CCS Directive and the long-term assessment of the technology. The EC had the competence to determine guidelines for national authorities on essential issues of the CCS, keeping legal frameworks under acceptable patterns.

As a multi-layered organization, the EU Members take different pathways to accomplish climate goals. Germany, for instance, may have queries about implementing CO_2 storage projects due to federative political reasons, once subnational governments could implement barriers to the CCS projects, or even consider offshore alternatives in their territory (Krämer, 2018). In contrast, EU members had improved mechanisms for reserving appropriate sites for imminent capture infrastructure in power plants, even though the CCS Directive was not mandatory (Velkova, 2018).

Although the legal frameworks have been implemented, the CCS business as a decarbonizing mechanism fails to establish a carbon market, which prevents potential agents from operating across multiple countries in the long run. Several barriers may have to be solved via public and private sector actions. Even though the CCS Directive has been implemented, the CCS activity failed to happen after more than ten years, and just a few large-scale projects are being implemented or in operation (Bassi and Boyd, 2015; GCCSI, 2021; Havercroft, 2018).

Institutional changes implemented to improve CCS large-scale projects and make them feasible have been insufficient to dissipate uncertainties as a rule (Bassi and Boyd, 2015). Barriers highlighted include risk assessment, access to pore space, ownership and leasing, post-closure, and liability. Research and development (R&D) consumed a significant budget dedicate to CCS by EU members in the demonstration project, while large-scale deployment funding was relatively absent (Budinis *et al.*, 2018; Osazuwa-Peters and Hurlbert, 2020).

In Europe, the incentives were designed in conjunction with other climate change tools. A critical issue was the carbon pricing mechanism, which has been decisive for the implementation of a low carbon economy and its technologies. EU-ETS was based on the requirement that GHG emitting agents present a tradable permit to cover their quota of CO_2 emissions. The European GGR target implied several changes since the beginning of the implementation process, such as the increase of linear reduction factor (LRF), market stability reserve (MSR), and the option to cancel its license (Bocklet *et al.*, 2019). In this system, the public sector has held auctions for the negotiation of permissions and the secondary mechanism to participate in the negotiation of the agents themselves bilaterally (Brink *et al.*, 2016; Raymond, 2019). Therefore, the system is coupled with the concept of budget and subsidies endorsed by public sector oversight.

In the beginning, the industrial sector received free allowances based on benchmarks developed for each GHG emitting product. After 2013, the Energy Intensive Industry (EII) received around 80% of allowances needed to cover its GHG emissions. The core of this policy was to protect sectors considered exposed to carbon leakage, which occurs when foreign competitors are not exposed to EU-ETS costs, being able to offer manufactured products without paying carbon price on the

European market. EU-ETS framework was contracted to gradually decrease free allowances until Phase 4 in 2021, when EII would have to participate in the license biding round to meet 70% of its needs. In 2027, it is expected to be 100% of them (European Commission, 2015).

Although carbon markets point to it as an instrument to improve CCS in Europe, the ETS was signed to introduce a risk that the industrial sector justified as incalculable, even with the expectation of rising carbon prices in the future (Åhman *et al.*, 2018; Cludius *et al.*, 2020; Compernolle *et al.*, 2017; Salant, 2016). The key issue is that ETS tends to level all emitters equally, and it is not enough to boost long-term investment across the entire CO_2 market due to the shift mechanism available to other uses, such as electrification, biofuels, and new sources of renewable energy generation which can cause a low ETS price.

Two additional directives provide a complementary framework. Emission Trade Directive requires the waiver of permits for the site emissions, which could help create financial solutions for leaks, while the Environmental Liability Directive brings harm prevention and remediation concerns to CCS activities (Makuch *et al.*, 2020).

The EII, as a group of emitters, has access to the improvement of current technologies necessary for the development of commercial carbon dioxide capture plants. For this, it is necessary to develop more efficient amine technology or other capture options.

We could deduce from their data, considering that incremental cost of final products could cause EII to lose market share to other producers who are not required to implement CCS (carbon leakage on global markets), that EII may have chosen a wait-and-see approach on the grounds that there is no concrete choice but to wait for a new institutional framework that reduces risks and does not cause loss of competitiveness.

A legal barrier to the carbon dioxide market between EU countries has been the restriction on international trade for waste dumping or incineration at sea, according to London Protocol, article 6. In 2009, the International Marine Organization Parties amended the international agreement to exclusively exempt CO_2 flows dedicated to Offshore CCS. To enter into force, the amendment must be ratified by two-thirds of the fifty contracting parties; however, it has only been ratified by fewer countries critical to the interests of Europe and by others – the UK, the Netherlands, and Norway as involved in CCS , and by Finland, Estonia, and Iran (IOGP, 2019).

Thus, institutional changes to have international trade based on the carbon market may require current diplomatic efforts from future stakeholders or alternative path to make carbon dioxide transfer feasible. (IEA, 2011b). Therefore, we deduce that drivers for the CCS in Europe should consider:

a. carbon pricing is still a mechanism to be considered in terms of economic viability of CCS projects;
b. free licenses do not encourage decarbonizing industrial projects.
c. long-term contracts need to be thought of to provide funding to make CCS viable as a nascent industry;
d. risks along the chain must be reduced or mitigated, but the transfer to a state-owned company may not be an acceptable cost-benefit.

Although storage projects are incipient, three countries have developed institutional foundations to try to improve CCS business in their economies: UK, due to the need to improve its industrial clusters and decarbonise its energy sector; the Netherlands, due to the main port of the Rotterdam cluster and its EII industries (steel, chemical, and fertilizer industries, energy sector or maritime logistics); and Norway, the only country with CCS projects in operation.

Also, unless in the offshore area, they may ban carbon storage activity due to social and political choices. Thus, its cases could improve the knowledge needed to reduce risks and transfer experience abroad.

5.4.1 Norway: the key to EU-CCS deployment

The Nordic country has been a trend-setter player in building an institutional framework for implementing offshore carbon dioxide sequestration. Since the 90s, policymakers started to work on the climate agenda, implementing a carbon tax system concerning oil industry GHG emissions in the North Sea.

The legal framework for Norway was built via the CCS Directive and using the petroleum activities act, of 1996, by interpreting its contents to provide the minimum legal stability needed once both sectors are closely symbiotic since the industrial growth process. In addition, the regulation establishes a fundamental framework required to reduce possible uncertainties on the CCS chain[12].

In terms of competencies, considering the political decision agents, Ministries of Petroleum and Energy (MPE) and Climate and the Environment have been responsible for CCS Storage and its activities in the continental shelf, segmenting tasks in the resource management and environmental issues, respectively, in which the first evolve similar licensing process observed on E&P, from prospecting to post-closure phase, adding those applied only to CO_2 storage, such as long-term liability and financial mechanism. In contrast, the environmental licensing process can be equivalent to the business as usual (Agerup, 2016).

Regulatory decision competes to each governmental agency linked to ministries. The Norwegian Petroleum Directorate and the Climate and Pollution Agency can be considered the critical agents to CCS projects once they have veto power on public policy implementation. The new agent established by the government was Gassnova SF, an SOE from MPE responsible for managing the national interest in the CCS projects, such as R&D, financing programs, and partnerships.

Since the Kyoto Protocol, Norway overtaxed final oil goods and upstream offshore sector. Initially, the primary fossil fuels were target via the ad rem carbon tax system in the gas, from US$ 43-49 per CO_2.tonne, and in the oil extraction, at US$ 51

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[12] Regulations to Act relating to petroleum activities. Available: https://www.npd.no/en/regulations/regulations/petroleum-activities/#Section-30c.

per CO_2.tonne on average (Bruvoll and Dalen, 2009). Subsequently, the State-Owned Enterprise (SOE) Statoil, currently renamed as Equinor, deployed Sleipner, the first large-scale CCS project, injected in the Utsira Formation CO_2 from the natural gas processing plant (NGPP) to avoid paying carbon penalty, then evading the new tax system. Therefore, pricing carbon emission has been capable of incentivizing GGR, and, more recently, in 2014, the tax system to increased up per tonne tax up to US$ 69 (Bruvoll and Larsen, 2004).

To join in the EU-ETS, the Norwegian government has opted to change the legal framework of the national GHG emission trade, and both systems were matched in 2013. The Greenhouse Gas Emission Trading Act was enacted in 2005 and wholly harmonized in 2013. Most of the GHG emissions is under the trading system have been covered or by EU-ETS or by a national carbon tax. Regulatory requirements have also been used as a path to improve CCS activity. For a low GHG emissions level, constraints are being imposed to license oil fields unless technical concerns justified gas ventilation in upstream offshore facilities.

Institutional enforcement for CCS Offshore was low hanging fruits and the governmental capacity to induce the economy via SOE.

The first mechanism implies capturing the cheapest carbon dioxide in the NGPP-Capture facility. In general, raw natural gas must be separated from other phases before transport and available for consumers. Due to its cost, economic business assessment inclines to pick the gas reinjection when the cost is higher than its sales revenue. Then, once opt to produce, the separation cost for capturing phase is drastically reduced.

The second is linked to the SOE to reduce CCS's business risk through its chain. Corporate verticalization advantage the oil industry and the public companies. Moreover, the operator's major shareholder and the regulator's duties, transferring the liability process from operator to the government, tend to favor due to double public custody.

Both Norwegian cases, the Sleipner (1996) and the Snøhvit (2006) large-scale CCS projects, fulfilled those instruments, highlighting the aspects of being into the oil industry and NGPP-capturing plant and low cost of CO_2-capture, being managed and operated by the SOE Equinor, supported by carbon tax under Norwegian legislation and by the government (GCCSI, 2021; Reiner, 2020).

Despite that, the Sleipner gas field's feasible factor was the natural gas compulsory separation process, which released carbon dioxide to capture. In addition, the saline aquifer in the Utsira formation, the selected geological storage, represented a low cost to the whole project, about US$ 17 per tonne, considering the tax penalty for the gas ventilation’s alternative (Herzog, 2017). The Snøhvit gas field captures carbon dioxide in the LNG plant, transporting in 153 offshore pipelines to store in the Tubaen sandstone, one of the most bottomless offshore storage units in operation overpressure issue that has not been identified during the designing project phase. However, it allows changing operation plans efficaciously (Krevor *et al.*, 2020). Both Norwegian in operation projects represents long-running CCS from natural gas.

The Norway CCS project is the Northern Lights, in which the onshore captured carbon dioxide the from cement industry and the waste-to-energy facilities in Eastern Norway, the carbon dioxide transported by ships until the Norwegian west coast facility, and by the seabed pipeline to the Troll field (IOGP, 2019). This project can be an essential player in the environmental policy of E.U. and the international carbon trade. Being prosperous, countries with public resistance to implementing storage projects in their territories would opt to export the GHG captured to Northern Lights, achieving a double gain for parties. However, this mechanism, dependent on the London Protocol amendment, effectively enters into force.

5.4.2 Netherlands

Along with the high GHG emission industries stablished in the Dutch port area, the energy sector represents one of the main stakeholders for the implementation of CCS. however, from political choice to the effective emergence of decarbonizing business clusters, it is necessary to assemble a complex and detailed tangle of rules, thus reducing business risks.

Following the CCS Directive, the Dutch legal framework chose to amend the Mining Code to deal with offshore storage and the potential CO_2 international trade under OSPAR, land use guidelines and environmental rules (de Vos, 2014).

The development of CCS in the Netherlands started in the 2000s. Two pilot projects were implemented for underground storage from the capture of carbon dioxide from natural gas in the K12-B North Sea Block (de Vos, 2014; Lako *et al.*, 2011). Despite the onshore potential, the government decided to only allow offshore storage, noted during parliamentary debate the Barendrecht project licensing process, justified by the safety narrative and heightened public opposition (Van Egmond and Hekkert, 2015).

The government outlines the decisions and actions necessary to provide the conditions for CCS. To this end, the recently cancelled ROAD project examined the liability applicable to the operation of the business, concluding that in many cases, liability could be flexible, except for climate issues (Havercroft, 2019).

Licensing processes are combined into three licenses. The all-in-one license is under the Ministry of Economic Affairs and covers the entire CCS process, applied to commercial projects guaranteeing, for example, environmental aspects, while the second license refers to emission permit under EU-ETS. The CO_2 storage permit is covered in the Mining Code and related to CCS Directive operational concerns such as risk management, monitoring, site closure, and post-closure (IEA, 2016).

From the literature and legal analysis, we found that critical issues about CCS stakeholders were discussed in the Dutch Roadmap:

a. how could the CCS help to reduce carbon dioxide emissions;
b. the role of R&D in advancing CCS technology and building stakeholder capacity to address the challenge to scaled-up CCS;
c. the support to accelerate and economically deploy the CCS;

d. establish short, effective, and transparent procedures to develop and implement CCS projects; and
e. The sufficient certainty needed by CCS about long-term spatial planning, long-term political commitment, and economic viability.

Currently, there are few large-scale Dutch CCS projects. Porthos is the third large-scale project under development in Europe, located in Rotterdam, a substantial world-class industrial cluster potentially capable of capturing evolving project partnerships from BP, Shell, Gasunie, the Dutch Port Authority, and EBN. Nevertheless, it remains to transfer the facilities to a public-private consortium responsible for transport and storage phases. The Athos is an industrial consortium capture project in the steel industry between Gasunie, Port of Amsterdam, EBN, and TATA Steel. This project focused on a complete chain of CCS from the steel mill and transporting it to offshore depleted gas fields. The Magnum project aims to transform Norwegian natural gas into hydrogen to feed Groningen power plant, , that is, to produce energy from blue hydrogen (IOGP, 2019).

Finally, the Dutch institutional framework is supported by previous experience from the natural resources industry, depleted offshore oil fields as the primary storage reservoir, already built infrastructure, and SOE or equivalent government entity at the operating level. The competent political authority appointed is in the Ministry of Economic Affairs, and the legal framework is in the Mining Code.

5.4.3 The United Kingdom

The basic assumption of UK policy may be the national authority on CCS issues as part of its challenges to address climate change and ensure energy supply under low carbon economy patterns.

In the CCS Directive, the British government improved the legal framework for petroleum to provide a mechanism to allow storage. The path selected to transpose from the EU regulation into the UK legal system was the amendment of the Energy Act 2008, which provided the CCS licensing regime for offshore storage and The Storage of Carbon Dioxide. Regulations, complementing other EU requirements, entered into force in 2010 (IEA, 2012, 2011c). Therefore, the UK selected a model using an amendment of existing oil regimes to incorporate and establish carbon storage rules (Havercroft and Macrory, 2018).

The competent authority for CCS depended on CO_2 storage and the government function affected. In the first model, the Secretary of State for the Department of Energy and Climate Change (DECC) was responsible for initiating a project and authorizing CCS activities, and the Health and Safety Executive regulated general carbon dioxide hazard issues.

Under the Theresa May's leadership as Prime Minister, the government agency's industry-related policies and institutional CCS competencies were reshaped, segmenting public responsibilities into two parts, as follows[13].

The Energy Act 2016 changed the distribution of competences, reducing the agents participating in the CCS licensing, supervision, and regulation process. The Oil & Gas Authority (OGA) was given a regulatory role, enabling the ability to induce best practice in the regulation of the CCS chain, except for the licensing process in the Scotland territorial Sea (12 miles), which remained within the purview of the Scottish Ministers.

In addition, the British government created the Department for Business, Energy, and Industrial Strategy (BEIS) merging the DECC's political authority powers with the business branch. Then, BEIS assumed CCS policy competencies, with regard to abroad vision across the CCS chain, seeking to drive it, among the new CCUS Council, a ministry-led policy made up of government, senior management of the private sector, universities, and third sector, to review, monitoring and advise the government on the new CCUS industry approach 14.

[13] See the energy act amendment, in 2016. Available at https://www.legislation.gov.uk/ukpga/2016/20/part/1/crossheading/the-oga-and-its-core-functions

[14] Available at https://www.gov.uk/government/groups/ccus-council. Access: 24 Apr. 2021.

Moreover, potential operators must have a lease agreement (AfL) granted by The Crown States, providing the right to coincident pore space in time and place with the permission of the CCS, and a license from the Marine Management Organisation (MMO) to perform offshore residual activities (Havercroft and Macrory, 2018).

In conclusion, in relation to the UK allowing only offshore CO_2 storage, the main entities enabled for CCS were the regulatory agency OGA, and BEIS, filling public policy purposes, and the Crown States for pore space rights.

Although the CCS Directive requires competitive access to geological CO_2 traps, the government chooses to balance new oil rights and existing oil licenses, encouraging the current O&G sector to develop storage in existing oil fields. Currently, OGA has received three license applications, where competition was not possible due to the absence of a second notice within the deadline[15].

Once the UK got over key legal issues and institutional arrangements of public bodies, there remained a lack of incentive issues that could make CCS business friendly as a rule.

First, they implemented project funding mechanisms, but without achieving their goals or just failing. The Peterhead demonstration project failed due to political options to consider such funding to choose winners, in which CCS competitions either imposed too much constraint via procurement process or political majority change.

For example, in the second CCS competition, they proposed a capped capital budget of £ 1 billion for CCS projects through the Cost for Difference (CfD), and, before biding, cancelled the entire process (Reiner, 2020). Then, it allows inferring changes in priorities in the government budget to mitigate action plans (Cozier, 2016). In addition, funding innovation that could drive CCS has not brought enough results to grow its business, unlike other low carbon energy technologies

[15] Available at https://www.ogauthority.co.uk/licensing-consents/carbon-storage/. Access: 24 Apr. 2021.

(Reiner, 2020). Therefore, the applied mechanism has been unable to pay the cost of CCS at all stages of the chain.

The second comprises the public participation factor, which can be a risk while the technology is considered new and complex, although less resistance is expected for the offshore storage phase (Lewis and Westaway, 2018).

The third bottleneck is the long-term liability, which introduces enough uncertainties to increase the business risk, raise the discount rate, and make the project unfeasible. This issue is compared with what the nuclear sector has done with final disposal sites of radioactive waste from thermopower plants, usually under government supervision. The UK is currently trying to improve contemporary legal and institutional instruments to allocate long-term storage risk from the private sector to a public entity and then support industrial Hubs for CCS such as Net-zero Teesside and Zero Carbon Humber. The main objective of these efforts is to address the challenge of decarbonization in their industries.

5.5 THE USA AND ITS INSTITUTIONS TO INCENTIVIZE CCS INFANT INDUSTRY

The milestone for CCS activity was in 1972, in which the Terrel gas processing plant supplied carbon dioxide for EOR using0 a long-distance pipeline (GCCSI, 2021). Currently, the main large projects in operation are in the USA, accounting for about 25 million tons of CO_2 per year stored capacity, divided into ten installations, from emissions from the electricity sector, natural gas processing plants, fertilizer, hydrogen, and ethanol production as capture phase sources (Beck, 2019). The scenario currently observed is result of multiple efforts made by the public and private sectors.

Over the past few decades, the budget had indicated primary interest in CCS technology, awarding US$ 3.4 billion to the DOE CCS R&D Program through the Recovery Act (FutureGen and Clean Coal Power Initiative Projects), and subsequently authorizing seven large-scale CCS demonstration projects via The Energy Independence and Security Act of 2007 (Folger, 2016, 2014). Therefore, the Department of Energy figured as the Political Authority that gradually increased its influences on the CCS issue via the federal budget.

The Department of Treasury has also become a critical Political Authority due to its guidance and holistic view of budget allocation and implementation processes that ensure the adoption of sustainable practices considering the goals of GGR. For example, recently, environmental concerns needed to be considered alongside social and economic assessment under US Treasury-funded project grants (Treasury Directive nº 75-09[16]).

The milestone for CCS to be considered a tool in US climate policy was the Massachusetts vs. EPA, in which the U.S. Supreme Court interpreted the competence for the Federal Government's Environmental Protection Agency (EPA) to regulate GHG from stationary emitting sources under the Clean Air Act (U.S., 2007), but did not resolve latent conflicts between the agents involved in GHG pollution and energy policies due to fragmented and incomplete legal frameworks, resulting in aggressive litigation (Gerrard and Gundlach, 2018).

A derived consequence was the empowerment of the Federal Executive Branch through EPA regulation, resulting in the current framework made from the current regulation to build a comprehensive CCS regime (Havercroft and Macrory, 2018). Into its umbrella, EPA has set guidelines for carbon storage injection wells (Class VI Guidance) to protect underground sources of potable waters. In practice, it pointed to a key instrument to stimulate the environmental licensing of onshore CCS projects and the development of CCS state laws. In addition, the emission standards for EPA licensed project mandated at least partial adoption of the capture phase for new or modified coal-fired powerplants, despite necessary observation of state legal requirements that could run counter to political and technical positions from federal authority (Gerrard and Gundlach, 2018).

[16] https://www.treasury.gov/about/role-of-treasury/orders-directives/Pages/td75-09.aspx). Access: 28 Apr. 2021

The Internal Revenue Service (IRS) plays the role of Competent Authority in regulating tax credit instruments, which has been the main incentive for CCS projects in the US under section 45Q of the Tax Code. In 2008, legislation passed a provision of US$ 10 per ton of carbon dioxide storage via EOR and US$ 20 for other geological storage, both adjusted for inflation (Beck, 2019; Tarufelli *et al.*, 2021).

In 2018, the legal system was reformed to expand and improve. Then EOR tax credit rose to US$ 18 per ton and US$ 29 for dedicated geological storage, rising to 2026, where US$ 50 per ton incentive could be granted[17]. Thus, we infer that the IRS s is one of the competent authorities, however, applying only tax incentives.

For this, the Federal Government relies on Political — DoE and Treasury —, and Regulatory — EPA and IRS — Competent Authorities that make up the institutional framework to implement incentive mechanisms and maintain CCS best practices in the long term.

A handful of states improved their incentive mechanism cumulatively to the federal legal framework and its stimulus. In general, fossil fuels have been a significant economic resource that could be more interested in driving CCS implementation. More than 30 states have implemented their legislation to provide GGR rules, but half may be directly related to CCS and CO_2-EOR.

North Dakota has established a legal and regulatory framework similar to the oil sector; thus, state legislative delegates to the North Dakota Industrial Commission (NDIC) are responsible for acting as the licensing authority for carbon storage. The Commission manages key activities under state regulation, such as utilities, natural resources, public finance, and energy sectors, and the Council is composed of the Attorney General, the Agriculture Commissioner, and the Governor, who provided full authority for policy and regulatory decisions for the carbon sequestration phase.

Montana and Wyoming delegate licensing responsibilities to their oil offices (Board of Oil and Gas Conservation and Wyoming Oil and Gas Conservation

[17] https://uscode.house.gov/view.xhtml?req=(title:26%20section:45Q%20edition:prelim. Access: 15 Mar. 2021.

Commission), regulatory competencies related to carbon dioxide injection, and key rules that can reduce long-term uncertainties, such as liability term being transferred to the State[18]. In addition, Wyoming develops a second authority, the Department of Environmental Quality, for financial requirements.

Kansas' institutional framework has elected to apply comparable current entities address CCS challenges, legitimizing the Kansas Corporation Commission (KCC) to regulate and create guidance for a broad spectrum of carbon dioxide activities, such as closure requirements, financial guarantees and long-term liability (Ingelson *et al.*, 2010).

Regarding nontechnical risks, the states mentioned above have implemented institutional mechanisms to deal with long-term liability, reducing the post-closure location, making those considered incalculable costs by traditional private risk tools more predictable (Dixon *et al.*, 2015).

Illinois creates the Carbon Capture and Sequestration Legislation Commission to file a report evaluating CCS, and after defining the Authority of Illinois Commerce Commission to certify CCS activities. In addition, low carbon standards for energy, project financing for coal power plants and consequent GGR obligation, and tax exemption that provide incentives for current coal economy (EPA, 2019).

Even earlier Decatur Project was developed under the authority of the Regional EPA and funded the DoE and the State of Illinois. The project retained key lessons about regulatory uncertainties, the licensing process, and the possibility of a risk-based adaptive monitoring approach (CSLF, 2017).

New Mexico followed the path of the fossil energy generation subsidy, and its capture system, with a tax credit for GGR on thermopower plant and authorization for recovery of CCS on electricity[19], while Colorado opts for enforcement via regulatory incentives for partial capture in gas integrated combined cycle generation[20].

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[18] https://leg.mt.gov/bills/2009/sesslaws/ch0474.pdf and https://wyoleg.gov/2008/Session%20Laws.pdf
[19] http://legis.state.nm.us/Sessions/07%20Regular/final/SB0994.pdf
[20] http://www.leg.state.co.us/CLICS2006A/csl.nsf/fsbillcont3/AA1768EA6EB403A0872570CA007B8F34?Open&file=1281_enr.pdf

In Texas, the Natural Resource Conservation Commission is the authority to build and operate offshore CCS sites, and the Railroad Commission has been granted the competence to permit carbon dioxide sequestration activities[21].

In California, the Low Carbon Fuel Standard (LCFS) has been amended to include a CCS Protocol credit for a project that allows life – cycle emission reduction of fuel consumed in its territory (Beck, 2019), and also, projects under Sustainable Development Mechanism (SDM) serving LCFS located outside California. It can be inferred that CCS implementing cost reductions in the USA use federal and state systems, with an estimated break – even point between US$ 5 and 60 per ton of carbon dioxide (IEA, 2019).

In terms of CCS, most of a large-scale project in operation is in American territory. They total 14 facilities, 12 of which are in operation, from emissions from the power sector, natural gas processing plant, fertilizer, hydrogen, and ethanol production as sources of capture phase (Beck, 2019; GCCSI, 2021).

The scenario currently observed is the result of multiple efforts made by the public and private sectors, designing norms and institutions that allow the development of economically viable the CCS, in which the regulatory requirements of the Federal Executive Power and the states are adequately balanced.

Those facilities were made under common incentives that can be highlighted. The main facilities have low capture cost and/or transport, and carbon dioxide has been applied as EOR, such as Terrell (natural gas processing plant), Enid Fertiliser (fertilizer plant), and Great Plains (bioethanol production) (Havercroft, 2019). The American tax credit is widely used to enable the CCS from federal and state tax exemptions, credit, or subsidy. Few projects were supported by grants, and only one is vertical and dedicated to BECCS, the Illinois Industrial Project, where carbon dioxide is captured in the ethanol production plant (Beck, 2019).

Key areas were addressed to allow for the reduction of uncertainties. Several states institute that they will assume responsibility before EPA standards. For example, they transfer CO_2 ownership to the State after the site closure, or create a

[21] https://capitol.texas.gov/tlodocs/81R/billtext/html/SB01387F.htm

specific fund for long-term management, alternatives that reduce the risks of CCS business (Cleveland, 2017).

Besides, incentives other than the EOR are needed to make CCS viable. Financial support was used, example, to provide more than 60% of Illinois project funding (GCCSI, 2021; Havercroft, 2019). Therefore, generally, financial mechanisms are welcome to complement the tax credit for the economic deployment of CCS projects.

5.6 CANADA

Canadian model divided governmental competencies between the federal (central) and provincial autonomous authorities directly from the Constitution. With no hierarchy, and between their division of competences, non-renewable natural resources and property rights are traditionally subject to provincial regulation and legislation, so carbon storage matters have been under their control rather than the Government, and this could justify the incongruous improvements of legal frameworks in Canadian provinces (Krupa, 2018).

Central Government has been able to participate under themes adjacent to the CCS, such as seabed management, national borders, international relations, or national concerns, which can be seen in the transnational financing projects or interprovincial pipelines regulated by them, or constituent cooperation financing from above, down from central government to provinces (Krupa, 2018).

Regulatory requirements or standards are practical for small changes to infrastructure and facilities. Canada's Environmental Protection Act was amended to promote improvements in GHG emission targets. In 2014, it was amended to improve the reduction of carbon dioxide emitted by new coal-fired plants or that have reached the end of their useful life[22].

[22] Available on https://laws-lois.justice.gc.ca/PDF/SOR-2014-265.pdf. Access: 15 Mar. 2021.

CCS projects may be subject to the Environmental Assessment Act, under the Natural Resources Authority of Canada for access to government funding, and the intercountry pipelines are in the jurisdiction of the National Energy Board (Larkin, 2017). Furthermore, due to the new trend of environmental concerns in international affairs and the relevance of GHG issues, the central government could use this Act to regulate a set of CCS related projects, such as large-scale capture plants, transverse pipelines, and storage p, excluding the competences of the provinces.

British Columbia decided to modify the existing legal framework — the Petroleum and Natural Gas Act and the Oil and Gas activity Act — to incorporate boundary conditions for the construction of the new activity considering the current institutions well known to the agents, guided by the Ministry of Energy, Mines and Low Carbon Innovation, and regulated by British Columbia Oil and Gas Commission (OGC) as a part of its sector, unless the authority decides to reserve an area for agents interested in CCS; therefore, it is possible to waive the environmental assessment for CCS when developed under oil permit (Krupa, 2018).

The province of Alberta has a regulatory framework comparable to that of British Columbia. The legislation was adopted to cover other essential issues such as long-term liability, pore space access, ownership, and post-closure financing, providing the CCS Statutes through an amendment to the Mines and Mineral Act and the Energy Resources Conservation Act (Bankes, 2019; Krupa, 2018).

In addition, the regulation started using the Energy Resources Conservation Board, a quasi-judicial agency, the competent regulatory authority for O&G and is currently transformed into the Alberta Energy Regulator (AER). The AER regulation covers the CCS chain, considering the interpretation of carbon dioxide storage as an acid gas disposal in the oil industry, regulating the entire CCS chain if they occur only in its territory, therefore requiring environmental assessment and the approval of the Ministry of Environment and Parks (Bankes and Ference, 2010). Furthermore, the licensing process takes place under the Minister of Energy's responsibilities, so the AER and the Minister figure as the competent authority for CCS, in addition to those in the environmental assessment process (Alberta Province, 2012).

Saskatchewan has a similar legal framework to Alberta, providing rights to the “well owner”. However, the Environmental Assessment Act is also used and expands the Oil and Gas Conservation Act to cover possible projects since the agent could be examined by one or another legal path, considering the severity of the damage to the environment, and enabling more than just CO_2-EOR (Krupa, 2018).

In those three provinces, local regulation can enforce agent behaviour and set activities in the right direction. A key mechanism is the Orphan Funds, which provide a mitigation scheme for abandoned or damaged sites where exploration of natural resources takes place, leaving out third-party compensation. Thus, it could finance an alternative for long-term liabilities while they do not have an adequate maturity (Krupa, 2018).

Looking at the incentives, Canada has been doing CCS through Quest Project, operated by Shell on behalf of Athabasca Oil Sands project, a joint venture between Shell, Chevron Canada, and Marathon Oil Sands, in which three hydrogen producers via a methane reformer steam were upgraded (retrofitted) to capture and transport up to 1Mtpa of CO_2 and storage on the dedicated geological trap. The project has received public grants from the Governments of Canada and Alberta, which accounted for more than 60% of the required funding (Rock *et al.*, 2017).

Furthermore, the Canadian and Alberta ETS systems were implemented to promote a low carbon economy. However, those carbon market frameworks have been the subject of litigation between the federal government and Alberta, which calls on the supreme court to remove its federal carbon tax obligation.

The second project executed in Canada is the Boundary Dam coal-fired power plant in Saskatchewan, adapted to capture 1Mtpa of post-combustion CO_2 from SaskPower, via amine and transport it to EOR storage. The project has received public grants corresponding to almost 25% of the total funding required, and it has complied with environmental regulatory requirements for GHG emissions. Thus, Boundary Dam has to adapt to new emission standards for coal-fired power plants (De Nier *et al.*, 2015; Honegger and Reiner, 2018).

Although funding has been vital in Canadian projects, political issues can put CCS projects out on climate solutions for them. Considerable public funds supported both large-scale CCS projects in Canada, and during the election process, opposition parties used CCS funding as a counterbalancing issue and, once they win, allows inferring that new funding for CCS projects could be the object of political opposition (Reiner, 2020).

In short, the Canadian framework shows strong confidence in the regulatory procedure through the competent provincial authorities applied to the oil industry and environmental concerns. At the same time, the central government has prevailed in the financing role to encourage large-scale projects that can strongly affect national GHG emission targets. Furthermore, reliance on coal and oil for their export and energy production could reshape the importance of CCS in their future economy.

5.7 United Arabic Emirates (UAE) and Saudi Arabia

The Arab region should be highlighted as the most critical player in the oil industry, and current institutions play roles favourable to government intervention in the economic sector through the use of SOE or semi-public entities. In terms of CCS projects, both countries have one project in operation each.

The mains frameworks in force are the international agreements related to CCS, such as Kyoto Protocol, UNCLOS, and Paris Agreement. The possible way to introduce better rules for CCS has been the alignment with the current oil and gas frameworks and agreements, and institutional changes considering the improvement of ad hoc domestic regulation and the economy based on public capital, which is generally poorly regulated, and the challenges of implementing these CCS regulations or transferring the necessary technology (Tsai, 2014).

Saudi Arabia, for example, is highly dependent on international oil trade, based on public investment, guided by the oil company Saudi Aramco, and, considering the lack of a legal and regulatory framework for CCS, only the integrated chain via the SOE and governmental capital is viable (GCCSI, 2021; Liu *et al.*, 2012; Rahman and Khondaker, 2012)

Saudi Aramco deploys Uthmaniyah CO_2-EOR Demonstration project, sourced from an LNG processing plant, capturing around 0.8 Mtpa of carbon dioxide, which is transported to Ghawar oil field for EOR via a 70 km pipeline. Like the UAE project, Uthmaniyah is fully controlled by the government, which has proposed a less responsibility during the project life cycle and cross-chain risk due to the fact that the entire Saudi government is controlled vertically.

The Al Reyadah CCS project, executed in the UAE, is the only current example using capture carbon dioxide from the publicly-operated steel mill via Abu Dhabi National Oil Company (ADNOC) following the acquisition of Masdar's share in the previous join venture. It is dedicated to capturing gas from Emirates Steel at the end of the process for the production of syngas by methane reformer, which is released as a residue a mixture of CO_2 and H2O (Fan and Friedmann, 2021; Sakaria, 2017). Afterwards, the molecule is transported through 43 km of pipelines, and used for EOR in the onshore oil field of the Emirates onshore oil field, replacing natural gas, and, consequently , leaving methane available to the domestic market (Koytsoumpa *et al.*, 2018).

It is important to highlight that State controls all companies involved; therefore, political risks or financial concerns may be overlooked by the evaluation process. The UAE government bears all risk, commercial, technical, long-term liability, and cross-chain in short.

5.8 CHINA

The Chinese economy has been the most significant GHG emitter. Recently, its government announced the net-zero target by 2060, which implies enormous efforts from hard-to-abate industries, which are coal-based, and which consume half of the global market share of cement, iron, and steel (Pee *et al.*, 2018).

Previously the government has already updated its portfolio of CCS projects through the CCUS Roadmap (GCCSI, 2019). Although the Chinese government has defined a comprehensive regulatory regime, main issues could be solved using comparable legislation, such as radioactive waste regulation, Mineral Resources Law, Environment Protection Law, considering the institutional framework involved in energy decision-making or related sectors (Huang *et al.*, 2014).

For the licensing process, the absence of the competent authority of CCS presents a perspective for similar sectors. Therefore, the capture from thermopower plants would have the approval of the provincial agent, National Development and Reform Commission, and National Energy Administration, while the offshore storage would receive the approval of the Ministry of Land and Resources and related governmental offices (Huang *et al.*, 2014).

The CCS Jilin Oil Field Project has been in operation since 2018 by CNPC, and it is dedicated to injecting EOR carbon dioxide into low permeability reservoirs of the Jilin oil field in northeast China. The capture process takes place in a natural gas processing plant, separating gas fractions from the Changling gas field, transporting it to the Jilin oil Field at around 0.2 Mtpa, reaching 0.8 Mtpa (GCCSI, 2021).

The ownership of all infrastructure and inherent risks are SOE or government, and the capital needs to support the CCS project come from a surplus oil production at Jilin Oil Field. It is expected to inject over the life of the 29.6 mega tons of carbon dioxide, resulting in an extra increase of oil produced between 12.8 and 17.6 Mt (Zhang *et al.*, 2015). Demonstration projects are being implemented in China, and are mainly linked to EOR or power sector, operated by SOE and under government support (GCCSI, 2021; Yu *et al.*, 2019). Thus, in the same group as the UAE and Saudi Arabia group, China has been applying a model in which the government is the main vector of CCS activities, risks, and opportunities in GHG mitigation policies.

5.9 WHAT COULD BE LEARNED FROM CCS KNOWLEDGE AVAILABLE IN THE EXPERIENCE?

More than a decade after the first consistent improvements to CCS, only a dozen projects have been implemented.

In Australia, CCS technology emerged on the political agenda concomitantly with the enactment of the Kyoto Protocol. They were the pioneers in promoting efforts to develop industrial processes of clean energy technologies to be used in the synergy of available fossil energy sources, since in main systems they were not able to fully internalize the environmental costs involved (Ekins *et al.*, 2017). In addition, its behavior changed after political changes in 2008, when the Labour Party took over as Prime Minister, and CCS moved to a proactive stance. Then the Liberals took over the government and cut the CCS budget by around 70% after campaigning against Labour Party's climate-friendly agenda (Reiner, 2020).

In Canada, the environmental agenda has been in the political arena, and CCS projects are being targeted against the incumbent, resulting in reduced financial support for long-term projects in the event of a change of Executive Branch (Reiner, 2020).

Therefore, from a pendular political oscillation, institutions involved in CCS or any climate agenda that can be confused with political debate tend to deteriorate and improve the costs involved.

On the one hand, international stakeholders pointed to resolutions based on carbon markets, carbon pricing process, and regulation to promote efficiency through supply chains.

If the global market overwhelms high emitting industries to reduce GHG, it could cause deterioration of international market trade in resource-rich countries, such as Canada, Australia, UAE, and Saudi Arabia, and reduce natural resource rents. CCS fits as a perfect solution to all possibilities of avoiding a low carbon attempt in the fossil fuel sector.

The Commonwealth has institutional organizations that segment responsibilities between the national and subnational levels, perhaps for the same sector, to have a conflicting interest.

In Australia, when the federal level improved legislation to allow for better conditions of long-term liability, the sub-national levels had no duties to follow suit Fewer states silently decided to keep the previous legal framework, thus reducing the possibility of maintaining green business in the long run. The exemption is the Gorgon project, low-hanging fruit, and a world-class natural gas project joint venture of major oil companies. The GHG is easily captured after the natural gas processing plant, and the costs were considered adequate under a specific legal framework approved just for this, representing a nascent industry.

In Canada, provincial governments were able to deal with the overarching institutional framework, while the Central government can finance or take on strategic projects in terms of environmental and international relationships. In summary:

i. coordination between national and subnational levels may be the main challenge;
ii. excessive legislation can overshadow the legal framework and generate uncertainties without a cause and effect factor;
iii. for the nascent industry, wasteful regulation implicitly means decision not to encourage CCS technology.

The USA has built a resilient and robust institutional framework for the CCS business. Environmental framework provided by the EPA or equivalent state agencies, addressing one of the critical issues on its chain.

Moreover, the adoption of oil regimes, best practices, and remaining facilities (infrastructure) accelerates the learning curve for CCS and for this, the large US state producers were the most encouraged to implement institutional conditions to develop large-scale projects.

It is also noteworthy that since the first CO_2-EOR project, in 1972, carbon dioxide capture and transport phases were integrated into oil clusters after the US fields reached their production peak in 1971, which justified the increasing of EOR methods. In addition, they have implemented well-known and tested national and subnational tax credit incentives. Therefore, the costs associated with the CCS chain can be more competitive than in other countries.

Singular liability schemes or public funds were created to transfer ownership of the injected carbon from the operator to the public agent, so the issue of long-term liability introduces nontechnical uncertainties in the economic valuation of CCS projects, exonerating main unsolved future risks.

In addition, The Federal 45Q tax credit and the Californian carbon market provide a profitable long-term incentive to make CCS projects feasible.

A distinctive and typical arrangement is linked to SOE usage and unanticipated risks when considering the privately based project. To this end, multiple market failures were resolved by transferring them to the government, such as long-term liability, minimum price schemes, or infrastructure operation, what could provoke intimidation or coercion by the private sector along the chain and between sectors of GHG.

Finally, coordination instruments for the implementation of public policies and their institutional and regulatory models could define how the GHG emitting sectors would relate to each other, sharing costs and benefits collectively. Specifically, governmental actions can improve or reduce the uncertainties that define how feasible the viability of large projects.

Relevant aspects highlighted for current large-scale CCS projects globally have been, the emission credit or tax credit (USA, Canada, and EU, by EU-ETS); the carbon tax (Norway); the low-hanging fruits and EOR; the grant support (the USA, and Canada); the regulatory requirements (Norway, USA, and Canada); and the SOE or governmental intervention (UAE, Saudi Arabia, China, Norway, and Canada). The table 5.1 below summarize it:

Table 5.1. *Main institutional features in the framework of selected countries.*

Country	Legal Framework	Liability	Incentives	Notes
Australia	Multiple Frameworks (Subnational and Federal) Offshore: veto power Barrow Island Act	Undetermined or 20 Years Gongon Project	Grants Regulatory requirements, verticalization	Political wave Natural resource dependent
The USA	Subnational framework, and infralegal rules by the Federal	In major, solved by Estates engaged on CCS by transferring to public sector	45Q (Federal) EOR, Infrastructure, LCFS, Grant support	Incentives compensate the activities risks. Liability well defined
Norway	Directive 2009/31/EC, Directive 85/37/EEC, European Green Deal and Climate Law, National laws	SOE/SCO	SOE/SCO, Carbon tax, verticalization	The country would provide solution to the neighbours
The UK	Directive 2009/31/EC, Directive 85/37/EEC, European Green Deal and Climate Law, National laws	Remained unsolved, but the government is dealing with	EU-ETS Grants	Dealing with long-term liability
The Netherlands	Directive 2009/31/EC, Directive 85/37/EEC, European Green Deal and Climate Law, National laws	Remained unsolved, but the government is dealing with	Low-hanging fruits, EU-ETS, public intervention	Dealing with long-term liability and grants.
China, Saudi Arabia, and the UAE	???	SOE	Public intervention	Lack of information. Mostly, the public sector develops CCS projects.

Source: author.

5.10 CHAPTER 5 REFERENCES

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6. DESIGNING INSTITUTIONAL FRAMEWORK: THE BRAZILIAN COMPETENT AUTHORITY ON CCS ACTIVITIES

6.1 INTRODUCTION

The twentieth century was marked by global economic growth resulting from industrial and technological progress and the indiscriminate use of natural resources, such as fossil fuels in electricity, industry, and transportation models that revolutionized mobility and daily urban activities in large cities. However, there was an increasing concern that those activities' current benefits could compromise future generations' well-being, and problems caused by climate change needed to be addressed.

Processes related to the use of natural resources and economic development embodied the National Conference on the Human Environment, in the period between 5 and 16 June 1972, the Stockholm Conference, and, for following decades, those of climate change concerns have been added by policymakers and began to demand more concrete actions from nations of the United Nations.

One of the most important events was the Paris Agreement, which entered into force on 12 December 2015 due to intergovernmental efforts to ratify the Parties' 21st Conference (COP 21). It can be considered a diplomatic success as several nations begin to make efforts under the aegis of a legal instrument beyond diplomatic nature and bring obligations to the signatories (Klimenko *et al.*, 2019; Savaresi, 2016; Viñuales *et al.*, 2017).

Thus, the growing demand for solutions to mitigate GHG emissions at the global level has promoted the expansion of research to enable large-scale projects on industrial sectors to use CCS technology and has brought up the academic sciences to support those improvements. Recently, there has been renewed interest in implementing CCS large-scaled under global strategy to tackle climate change issues (IEA, 2020b, 2020a).

Concerning CCS in Brazil, studies over the past decade have provided some information about the legal system, possible configuration among sectors with high GHG emissions, as well as civil liability (Jose Ricardo Lemes de Almeida *et al.*, 2017; Costa and Musarra, 2020; Costa *et al.*, 2018; Moreira *et al.*, 2016, 2018; Musarra *et al.*, 2019; Romeiro, 2014).

Besides that, for Brazil, they highlighted being a challenge to be faced and overcome the acquiescence of a specific legal framework of CCS, and the current issues have focused on the theme analysing of the Brazilian CCS technology policies. Results on the legal framework in developing countries indicate the need to adapt to the reality of each territory (Romeiro, 2014), such as studies on civil liability regarding the storage of carbon dioxide and on the ownership of the injected molecule (Morbach *et al.*, 2020a; Musarra *et al.*, 2019) and as decommissioning of projects (José Ricardo Lemes de Almeida *et al.*, 2017).

However, a relatively small body of literature is concerned with the competent authority's role, and the Brazilian CCS institutional framework has not been appropriately investigated. Understanding the definition of competencies and the institutions and agent's behaviour involved in GHG's national emissions can help policymakers better deal with implementing the challenge of new storage projects in terms of economic effectiveness.

Moreover, through appropriate authorities' designation to handle CCS, a suitable arrangement of the institutional system may diminish risks hard to reduce linked to policies, cross-chain, and storage liability risks (Rassool *et al.*, 2020; Zapantis *et al.*, 2019).

This chapter provides an overview of the normative and institutional framework compatible with the distribution of gains, costs, and risks among the CCS economic chain. It will be examined the relationship between the agents involved, as well as the allocation of legal responsibilities to each party associated (government, private sector, and consumers) and the adequacy of institutions for the development of CCS in Brazil, mainly on negligence avoidance by the private sector and of insertion of risks exogenous to the activity by the government.

The purpose is to be pointed out the role of both competent authorities for the CCS policy and the regulatory function, focused on legal assignment distribution as a path to reduce risk and incentivize the private sector to improve CCS large-scaled projects. In that context, it will be investigated the dilemma of multiple authorities, the inertia resulting from diffused interest in the public sector, and recent cases of empowerment of authorities related to the economic sector. Thus, the critical question is: who would be the competent body to authorize and regulate CCS activity in Brazil?

The following section will briefly overview Brazilian engagement in the Paris Agreement under CCS activity's current legal gap. The third will be concerned about the institutional framework on competent authority to Brazilian case. To this end, the fourth section will discuss the perceptions of this research for final considerations.

6.2 THE INTENDED NATIONALLY DETERMINED CONTRIBUTION (*i*NDC) FOR BRAZIL AND THE ABSENCE OF THE CCS

For the energy sector, the Brazilian NDC is based on expanding electricity generation by renewable sources, using bioenergy for the fuel sector, improving energy efficiency for industry, and deploying low carbon infrastructure (MMA, 2018). However, climate change policy has been acquiescent on incentivizing CCS projects directly as a mix of solutions to tackle GHG emission abatement and its NDC targets.

The country's strategy to the energy sector, by inference, is tied to the planning of the expansion of the electric power generation facilities, to the energy efficiency program, and the targets for mandatory mixing and use of biofuels, which represents a coercive stimulus based on control of supply chain of fuels and the mandatory use of low emission energy source to achieve long-term CO_2 emission limits.

On the one hand, this path allows inferring a strict choice by non-GHG emitters source. On another side, it ceases promoting mechanisms to encourage existing fossil sources' decarbonization, remaining the majority in the energy mix. This evidence may have been an essential factor in the case of high emitters manufacturing showing difficulty to be encouraged to developing CCS sequestration project, other than enhanced oil recovery on mature fields or high-profit biofuels plants.

In general, only part of the actors along the production and consumption chain is perceived as responsible for GHG emissions in the atmosphere, such as the non-culpability of the final consumer or public transport users by carbon dioxide from burning fossil fuel in cars or buses. It is a prominent gap in the means to make the Brazilian NDC effective, and it can be overcome by improving regulations and institutions through a coercive capacity to shape the behaviour of the agents involved and to lead them and direct them to rationality in the use of resources from a holistic perspective (North, 1990; Ostrom and Ostrom, 1990).

Ongoing studies have pointed to the need to consider each country's legal and institutional specificities, using comparative institutional analysis, as far as possible, to understand foreign experience on CCS, such as in Europe, the USA, and Australia, and establish institutional frameworks. Thus, using the international comparative law to help Brazil establish its own CCS legal framework, then, transposing to the Brazilian institutional and regulatory reality.

6.3 INSTITUTIONAL COMPETENCIES IN BRAZIL

The distribution of responsibilities, benefits, allocation of costs along production chains has been a complex function in societies seeking a commitment to climate change policies. All these attributes represent exogenous input variables on the decision-making of economic sectors that produce goods and services used by consumers and improve whole well-being status, despite the unwanted pollution via GHG emission caused by it. However, the distribution of gains and losses has been set aside in the formulation of public policies.

Previous studies about institutions can help understand the effects of norms on society better once it can be effective in diagnosing the opportunism behaviour of agents under evaluation that short-term benefit surpasses the cost of its actions (Williamson, 1975).

Agents acting on the market, for some reasons, could need guardianship by the government to avoid unfair rules imposed by majority agents, to the detriment of the community; therefore, the government can occupy three positions, as the regulator, as a public policy implementing agent, and as a market agent (North, 1990; Williamson, 2005). It evaluates the damage caused by the regulated agent and the consequences of and suffer actions, or even if there are gains in the previous situation (Coase, 1960).

Economic efficiency means that the transaction cost would be zero (Coase, 1937). As this hypothesis does not occur in the real world, the institutional model, as far as possible, is responsible for reducing it by inducing the behaviour of agents from the organization of society and the relationship between law and economy, using long-term rules based on contracts (Brousseau and Glachant, 2008; Williamson, 1985). These solutions have been associated with a possible tendency to increase individual profit in the short-term, which would compete to the government the function of regulation and arbitrage on such agents (Hardin, 1968; Hodgson, 2003).

The institutional economy concepts support state action to change the behaviour of agents responsible for high carbonized industries. They are essential because institutional assessment should focus on allocative efficiency concepts when the global distribution of resources increases welfare state levels. The allocative brings about lower cost possible and sustainability, which means ensuring the welfare and sustainable development in an intergenerational way, to achieve the GHG emission reduction scenario into minimum transaction cost through improvements in Brazilian rules (North, 1990; Williamson, 1985).

Therefore, the lack of a holistic legal framework defining risks and responsibilities of CCS activity, and the behaviour of the institutions and agents involved in the country's CO_2 emission levels.

There is an unambiguous relationship between sovereign countries' decisions and the implementing process that implies changes in final agents' behaviour in the GHG issues. What happens is that there is an immense possibility pathway to be adopted and reshaping institutional systems can define whether they will achieve success succeed in their targets.

Returning to Brazilian legal frameworks, exploitation of natural resources counted with mature systems to the mining, oil, and underground aquifer. They can be considered well known by stakeholders due to the institutional behaviour of governments, Parliament, local communities, and concessionaries for decades, beyond a well-defined authority to deal with implementing policy process and with regulation.

Looking to CO_2 storage in a geological formation, the absence of an institutional framework includes various uncertainties to the possible business strong enough to keep potential investors away from it. Hypothetically, an agent who desires to deploy a CCS project under a region where previous concessions are in place, such as mining rights, will have to make agreements to ensure long-term rules. However, the position for CCS could be negative comparing how developed both institutions are, CCS and mining legal frameworks. A precisely analogous situation exists for the mining sector when it conflicts with the oil industry developing at the same site. Therefore, the practical result is the restriction of CCS activity only to dealers already established in the oil and mining sectors, in the areas where they have concessions.

Even for specific companies that need to use the activity, the absence of friendly rules at least too much risk to the viable CCS business. Thus, in Brazil, a normative and institutional framework is a key factor for the CCS in sectors that can be implemented without high societal costs.

As a starting point, the European Union works as an institutional laboratory on CCS themes. In 2009, it was established as the primary legal framework for developing technology (IEA, 2009b). The CCS Directive provided mechanisms to ensure environmentally safe geological storage, rules for transporting and choice of site, adequate liability for damage to health and property, and removing some institutional barriers. In sum, it represented an important milestone for policies oriented to climate change mitigation in Europe.

Even though CCS in the EU continuous in the developing process, some advances have been observed. In line with the theme, the definition of a specific and detailed instrument as far as possible is more effective than the establishment of dispersed and excessively discretionary instruments (Kapetaki *et al.*, 2016), in which dichotomy between the concentration of power in monocratic authority and the fragmentation of competence between specialized organs was not well solved. Despite that, pilot projects have been executed to evaluate the dissipation of resistances concerning the effectiveness of the instruments used for CCS (O'Connor *et al.*, 2017).

Regarding competent authorities on the current Brazilian CCS institutional framework, it is possible to consider fewer insights from previous research on institutions.

Old institutionalism suggests the government has a hierarchical function, as a meta-institution above the others, dedicated to regulatory competencies in order to keep the evolutionary path of current institutions and to look for conflict's resolutions on reasonable terms within desirable changes (Bateira, 2010; Hodgson, 2003; Veblen, 1994).

New Institutional Economic suggests contracts can deal with solutions between parties, and, given that majority of agents could not process information holistically and to take decisions under rational choice theory, the government has to regulate them to potentialize advantages of path dependence through time (Fouquet, 2016; North, 1990; Williamson, 1985). Therefore, from both institutionalism aforementioned, the federal public agency is inferred for regulation rules (Costa, 2014).

An alternative path through institutions promotes minor enhancement on rules and after allows agents to cooperate to manage resources independently. Institutional Analysis and Development advocate that local users are competent to reshape institutions as an expected evolutive consequence and adequate them to communal needs, in which centralized government would be responsible for complementary rules and incentives instead of regulating any possible path just considering that individuals always assuming predatory behaviour (Ostrom, 2011; Ostrom and Ostrom, 1990). It emerges formulating and implementing policy functions, besides planning and incentivizing CCS activities, under authority competent, excluding regulating roles.

This section has attempted to summarize institutional literature that can support designing the CCS framework, framework, the current status of Brazilian normative[23], and an indicative path to divide governmental activities into two groups: general regulation and implementing policies to incentivize the CCS deployment.

The next topic focuses on previous studies recently done in order to try to distribute responsibilities between existing public agencies in Brazil.

6.4 THE FIRST PROPOSALS FOR THE DEFINITION OF A COMPETENT AUTHORITY FOR THE CCS ACTIVITY IN BRAZIL

A previous study of Romeiro (2014) has focused on the various elements of the CCS framework in Brazil, focused on the evaluation of several legal, regulatory, and institutional mechanisms that could be inserted in the Brazilian framework of CCS, which pointed out that given the multifaceted aspects surrounding a project and the long-term responsibility of CO_2, storage establishing a specific competent authority could ideally be the most appropriate approach. Nevertheless, since there is no significant demand for pilot projects, the Federal Government has neglected to establish a robust framework, defining regulatory authority and distributing responsibilities upon ministerial authorities in charge of implementing the policy process for CCS activity in Brazil.

Using theoretical methods to transpose practices and habits from one economic sector to another, a regulatory framework has been proposed, including critical issues and relevant steps to CCS projects (Costa, 2014). To better understand the mechanism proposed by it, Costa (2014) analysed a future CCS framework comparing to the natural monopoly on natural gas (NG) and oil sector, in addition to oil

[23] The detailed description of the institutional board related to the CCS issues in Brazil is provided in chapter 8.

industry regulation in Brazil, and she suggested National Agency of Petroleum, Natural Gas and Biofuels (ANP) as the competent authority for regulation, such as in Australia, unless the hypothesis of establishing a new regulatory agency, that would be under the Ministry of Science, Technology, and Innovation (MCTI) due to its relation to climate change policy[24].

Even prior research had already indicated ANP as a candidate for executing governmental duties because of its oil sector expertise. However, it highlighted the necessity of clarifying the whole CCS chain's competent authorities in Brazil (Câmara *et al.*, 2011).

Through interviews with experts, Araujo (2019) described some suggestions that ANP would be suitable for regulating CCS activities in Brazil since it has been responsible for regulating the oil industry under Art. 8 of Petroleum Law *in verbis*:

> Art. 8º ANP will aim to promote the regulation, contracting, and supervision of economic activities that are part of the oil, natural gas, and biofuels industry, with:
>
> ....
>
> IX – enforce the good practices of conservation and rational use of oil, natural gas, its derivatives and biofuels and preservation of the environment;
>
> X – stimulate research and adoption of new technologies in exploration, production, transportation, refining, and processing;

Besides that, Araujo (2019) informed that some experts argued that ANP had both expertise and experience on similar procedures and activities of CCS, for

[24] Despite the engagement of climate issues by this Ministry, it does not result expertise in the daily regulation of adjacent climate change sectors, then, insufficient instruments to deal with short-term needs for implementing incremental changes in the policy agenda.

instance: (i) regulation and supervision of hydrocarbon pipelines and reservoirs; (ii) right of access and storage of NG; and (iii) execution of bids for the granting of exploratory blocks, based on legal, technical and economic criteria which allow governance practices of natural resources of Brazilian market. Nevertheless, Romeiro (2014) asked whether ANP could make a suitable figure as the competent authority to develop some aspects, such as the conflict of interest between the activities already regulated by the agency or the capture risks by one or more chains.

Several stationary sources do not operate under a concession regime in the GHG capture activity, such as steel and cement. Therefore, they do not need to be supervised by the regulatory agency. Equally, thermopower plant and stationary hydrocarbon production units are regulated by federal agencies, despite just the second unit being under the legal jurisdiction of ANP to regulate the carbon dioxide capture.

It would be appropriate to have the ANP as a regulatory body on the transport stage only when GHG gas is carried out by pipelines regulated by it. Such pipelines could be converted from methane to carbon dioxide. Though, the obligation would conclude at the end of the concession contract or after the decommissioning stage. Consequently, on the hypothesis of converting old pipelines to carry carbon dioxide, it could be inferred they will need a new public call for granting the right of access and would emerge the need to have legal enhancements to establish this new competence for ANP. Alternatively, the transport of CO_2 by tanker trucks and ships could be done using the current legal framework and out of the oil sector's regulatory regime.

The carbon dioxide storage phase could be suitable for the ANP as regulatory authority only when it happens on oil fields or in mature reservoirs before the decommissioning process. Other cases in which storage is executed in exhausted fields, for instance, could demand specific biding for granting the right of access to the storage of carbon dioxide and would need legal improvements. Finally, storage options that remained, such as saline aquifers or coal formations suitable for CCS projects, would not fit the ANP's regulation.

Although CCS large-scale projects remained related to the oil industry, in its model, it has pondered that, in the long-term, it could be viable to implement BECCS nearby Parana Basin as a path to develop CCS industry (Moreira *et al.*, 2016)

Accordingly, to previous proposed, a National Committee for CCS activities would be divided as follows (Romeiro, 2014):

i. For the capture of CO_2, a member of the National Electric Energy Agency (ANEEL) would be responsible for regulating the capture activities on thermal power plants, and a representative of the ANP, responsible for regulating the activities of capturing CO_2 on oil fields. For the remaining sectors, it maintains absent who will be competent.

ii. For the transport stage, representatives of ANP, National Land Transport Agency (ANTT), and the National Waterway Transport Agency (ANTAQ) would be responsible for the oil industry, road transport, ships, and cabotage modals, respectively.

iii. For the storage of GHG, ANP, National Mining Agency (ANM), and National Water Agency (ANA) would be involved in the oil fields, the coal deposits, and the saline aquifers.

Despite the attempt to build a legal, regulatory, and institutional framework that seems to have sensibleness in conceptual terms, some models have neglected institutional changes. The studies would have been more interesting if they had included how institutions work on major emitters sectors and if they have explored the challenge to deal with many actors with a divergent interest in the same arena (Câmara *et al.*, 2011; Costa, 2014; Costa *et al.*, 2018; Romeiro, 2014).

The following section presents a perspective of effectiveness and institutional assessment of the CCS framework, inferring that it implies improvements on GHG capture by large-scale sources in Brazil.

6.5 THE ROLE OF COMPETENT AUTHORITIES FOR CCS ON BRAZILIAN FRAMEWORK

The pioneering works made in the last decade represented considerable advances in studies related to the CCS activities' legal, regulatory, and institutional frameworks. Under these bases, it is possible to assess what was proposed from the perspective of effectiveness.

Separating public burdens under a project assessment can improve how the private sector-owned industrial stationary sources of GHG see CCS viable. For that, pointing who are agents responsible for executing policies and guidelines and those that will keep regulatory power are the vital questions to shape institutions in favour of deploying new projects.

The study of Costa (2014) contributes to that; however, it fails to reshape guidelines and policy authority, makes no attempt to provide suitable solutions for civil liability at the end of the project, and avoids indicating appropriate authorities for key sectors capturing phase.

On the opposite side, the excess of agents linked to the regulatory agency may compromise the overall result.

The conflict of interest between technical representatives and the strong need for consensus in decisions may lead to delays in the approval of projects dependent on each member's manifestation. For example, if an agent brings more demand to its link location, it may use obstruction instruments until the plaintiff changes its design to a higher-cost alternative but accepted by the blocking agent. Regarding those concerns, discussions about competent authorities’ rules can contribute to achieving better answers.

6.5.1 The definition of guidelines for CCS activities: the role of competent authorities for public policy and regulation

The first function of the institutional framework is related to guidelines, implementing policies, and improving CCS activities through its chain.

The agents responsible for implementing industrial policies affected by climate change figures as the primary candidates to be elected as the competent authority for implementing the CCS policies. In general, they are expected to be involved with legislative negotiations to formulate legal obligations, propose miscellaneous incentives, maintain engaged ancillary governmental agencies under its supervision, and other pairs of the same hierarchy.

The figure of governmental planning also keeps a close relationship with the authority mentioned above. Those duties allow decision-makers to have a broad view of prospective scenarios, economic assessment of consequences for CCS on the internal market, or even increase of costs and its spillover for adjacent sectors (for instance, once GHG capture increase costs of energy, those sectors where the cost of energy impacts the price of the final product will be reasonably affected). The competent authority can do planning functions for policy implementation or any specialized agency directly linked to it. Therefore, we can classify them as Political Competent Authority (PCA)

Regarding the CCS chain, as a rule, it can act on early phases of deployment, dealing with different stationary sources of GHG, and establish rules and guidelines to distribute associated costs, to avoid rent-seeking behaviour, or to guarantee imposition of costs on certain groups. A myriad of instruments is well known by literature, such as cap-and-trade, command and control rules, carbon tax, carbon market, carbon pricing, and tax incentives (Allinson *et al.*, 2017; Compernolle *et al.*, 2017; Gomes *et al.*, 2009; Honegger and Reiner, 2018).

The next step deal with transporting carbon dioxide from the capture phase to the geological storage reservoir. Major studies pointed a correlation between pipelines operated by the oil industry and CCS transport facilities (Healey *et al.*, 2019;

Hodgkinson, 2014; Santibañez González, 2014), and natural monopoly regulation that allows multiple users to have equitable access to its resources (Hauge and Sappington, 2010; Mitchell and Woodman, 2010; Veljanovski, 2010).

At first glance, regulatory rules fit correctly as a significant activity instead of implementing policy.

It emerges, then, the figure of Regulatory Competent Authority (RCA), to promote regulation patterns and rules in order to balance costs into the CCS business chain and between agents, to ensure the maintenance of long-term contracts, to distribute potential gains of scale and technology applied, observing guidelines and legal obligations negotiated by PCA (Baldwin *et al.*, 2010; Geske, 2015).

Under RCA, the transport phase means legal and institutional frameworks are wholly incorporated into national jurisdiction, avoiding the gap for judication of conflict between entities.

Geological storage and final destination phase represent a fundamental challenge to CCS projects, once long-term and civil liability inputs uncertainties sufficient to growth costs without other technical motivation than the legal and institutional framework.

The access for geologic traps as natural resources needs to control critical issues, like the risk of carbon leakage by negligible after decommissioning, unselective process of access to a license, contractual rules to incentive best practices and loss of rights, free access to essential facilities and transferring long-term liabilities (Allinson *et al.*, 2017). Those rules provide defined rules addressed to environmental, health, and safety concerns, strictly related to regulation and RCA.

This section has summarized the policy and regulatory roles and consequential authorities, PCA, and RCA. Considering these perspectives, the next section, with the proposal derived from the pioneer studies, attempts to design those roles into an institutional framework for CCS in Brazil.

6.5.1.1 Designing the prospective institutional framework

The challenge for designing an adequate institutional framework for GHG reduction has to take into account the number of economic sectors involved, rigidness of current institutions that need to be slightly changed, and upgraded under pre-existent lock-in on industrial sectors, oil industry, and energy systems (Hansson and Bryngelsson, 2009; Tvinnereim and Mehling, 2018; Unruh, 2000). In terms of effectiveness, the prospective horizon and undertakings that can implement the CCS activity must be evaluated, considering that a small number of projects are candidates to be deployed in the coming decades.

This section proposed improvement and arrangement of a reflection on existing institutions' quality to undergo three paths considering these perspectives. It also means that adopting current institutions figures as a reasonable choice is more than scientific options. As an option, the possible disruptive formation of new institutions disconnected from existing ones to accelerate the CCS development cannot be ruled out.

6.5.1.2 First path: via an existing framework

The first pathway refers to the current framework applied to any CCS project. The formation of both legal and institutional frameworks acquiesces as to the normative applied to it.

As a mainstay, constitutional law condescends carbon storage rules, incentives, or even delegation, resulting in the absence of priority rules assuming underlying conflicts between agents dependent on natural resources, once the same geological structure can be prospectively interesting on mining, oil, water, or CO_2 storage. Thus, constitutional, legal, or normative framework is applied transversely and depends on hermeneutic interpretations.

As regarding Federal Constitution of 1988 (CF), it is possible to deduce that the Union has the right to use the subsoil, including the geological potential for sequestration of any kind of fluid (such as carbon dioxide or disposal of waste), as an ancillary activity reliant on significant sectors.

In theory, CCS as an accessory activity would avoid increasing costs of those activities using geological traps to obtain economic profit. Institutionalism supports that contracts can play an important role by having adjoining rules, property rights complementary to constitutional and legal rules, which would remain prevalent to private agreements (Brousseau and Glachant, 2008; Stone, 1986; Williamson, 1979). Consequently, mining and oil codes could give sustenance to CCS during the prior phase, and only the Union would have the competence to legislate about geological sequestration of carbon dioxide, notably based on energy and mining industries, leaving subnational entities aside from having a relevant role regarding this competence, on storage phase.

Regarding the transport stage, on-premise of the current legal framework, where the absence of legal delegation results in RCA's weakness, PCA could fulfil it and operate as both regulatory and political authority, despite it being undesirable for other participants CCS chain. Many governmental agencies are candidates to participate as competent authorities along the life cycle, and the energy sector has built know-how to deploy linear infrastructure under regulatory frameworks.

The agency responsible for regulating the whole electricity sector has implemented concession contracts to expand and operate high voltage transmission lines between regions testing regulation and unbundling standards appropriate to prevent rent-seeking behaviour and its resulting increasing costs (Hauge and Sappington, 2010; Veljanovski, 2010). However, transfer this experience to CCS institutional model is delicate due to the notable difference between an embryonic and well-established industry.

Likewise, the oil industry inputs backgrounds replicable to CCS in terms of distributing long-term gains and obligations. The natural gas (NG) pipeline industry has been working on concession and authorization regimes, sharing legal duties with the Federal Government and subnational states. In contrast, liquid fuels and crude oil pipelines institutional frameworks are related only to federal agencies. Nevertheless, both cases are entirely covered by legal regimes considerably consolidated and trustworthy by private agents involved.

The closest lesson applicable to CCS is iron ore pipelines in Brazil. There are fewer projects in operation, which were developed without a specific legal framework to deal with complexities inputted by world-class ore prospects under environmental authority licensing regulations. General roles denote RCA and partially PCA figures covered by competent environmental agencies from Union and subnational states when legislation is absent. So, it assumes public duties and ex-ante and real-time regulation of the CCS transport stage.

Through Enhanced Oil Recovery (EOR), Brazilian have experimented with carbon dioxide transport as the prior institution framework. This model was observed in the Miranga mature onshore field, in Bahia State. The operator opts to convert the transfer pipeline from carbon dioxide to the NG (Santiago-Camaçari pipeline), and turn back to EOR-CCS business several years after (Lavergne *et al.*, 2007).

For that, the operator request infrastructure reclassification via the Authorization nº 257/2002, and it resulted in transferring RCA from the Environmental Agency of Bahia State to ANP. To restart CO_2 storage, a new licensing and authorization process had to be submitted to the State Environmental Agency, which implies a type of twin projects being under at least, two competent authorities, directly involved in the transport phase, or adjacent at upstream and downstream NG chain.

The transport phase may represent a bottleneck in the chain in terms of business and the physic carbon dioxide flow. Even though the comprehensive legal framework would better address it bottleneck, it is possible to propose normative solutions under the current institutions.

The public sector can work as PCA in the network plan that tends to optimize the infrastructure facilities linking the capture cluster to the storage fields, embracing a carbon cluster. In the Brazilian institutions, the Energy Research Office (EPE), a public company dedicated to governmental energy sector, may provide data and studies that allow the PCA to do the network plan for carbon transportation. In addition, gas patterns need to follows standards of quality to access carbon pipelines, other transport modals, and the storage fields in order to avoid operational and safety complications.

Alternatively, the public sector could deploy transport facilities under administrative instruments that allow long-term contracts. The private sector designs, builds, finances, and operates an infrastructure, through the legal framework of public-private partnerships (PPP) and reduce political risks related to RCA and PCA, since they consider the collective needs of optimizing operation economically.

The capturing phase represents the most complex scheme to be regulated because each emitting source could respond differently to public incentives proposed by policy and regulatory paths, and the capturing cost matrix cannot automatically be imposed. For instance, the cheapest carbon captured on NG processing plants becomes natural candidates to target regulatory emission patterns.

In contrast, thermopower plants, fertilizer, and steel industry could be overwhelmed by the NG industry's same obligation. Despite that, the current framework indicates that government agencies responsible for regulating the economic sector are the main candidates for RCA functions. On the hypothesis of legal absence, environmental agencies precariously fill this gap.

Regarding PCA functions, the current legal framework application can reduce risks through infralegal standardization with the public administration's organization regarding executive coordination and obligations for each part-office agent.

This improvement could occur by executive order, in compliance with the National Climate Change Policy established by art. 84 of the CF and Law nº 12.187, of 2009, segmenting tasks and duties between federal agencies, like RCA, and their related ministries, as PCA. The main authorities evolved are the Ministries of Mines and Energy (MME) and of Environment (MMA), subsidized by EPE when the prominent sector is the energy. Remaining issues would be addressed by the MCTI

The result is a CCS assembly of norms that corresponds to adding fragments of governmental rules performed by its agencies and fulfilling several institutional frameworks needs but preserving sectorial agendas considered the main activity.

From this perspective, competent authorities to deal with capture projects to decarbonizing electricity generated by fossil fuel are Aneel and Environmental Agencies. At the same time, oil and NG production are ANP, as an adjacent activity to concession, production sharing, or onerous cession contracts in force, without need for changes in current contracts, thereby CCS activities would be subject to the standardization of the Board of ANP to regulate the disposal of waste from oil activity in geological structures proximal to oil infrastructure linked to the exploratory areas, and long-term risks will be considered into oil regimes.

Remnant emitting sources, such as cement, steel, and fertilizer industries, remain under the environmental agency umbrella. However, governmental decisions to obligate them to capture carbon dioxide could be postponed due to lack of incentives or to the complexity of arranging an efficient mechanism to avoid predatory competition on the international market.

In summary, it has been inferred that the current CCS framework implies that it would be necessary to evaluate the reasonable way to determine the technically competent agents beyond environmental authority for each CCS project or each enterprise. The burden would be the absence of patterns that can result in preferential treatment for a project concerning another, even in the same activity, or notably divergent decisions, such as refusing CCS operation to an oil field but granting it to another equivalent by the high degree of discretion on the executive branch. Table 6.1 provides a brief first path.

***Table 6.1**. CCS arrangement based on the legal framework in force.*

Suitability	Short term, based on institutions linked to CCS
Regulatory Competent Authority	ANP (oil and NG industry), Aneel (electricity), and IBAMA or subnational environment agency (remained GHG large-scale industrial plants)
Political Competent Authority	Federal Executive Branch (MME, MMA, and MCTI) and Subnational States' Governments, subsidized by EPE and other sectorial agencies.
Long-term Liability	ANP, provide by concession regimes of oil and NG frameworks
Remark	Political changes input high risk (obstacle to the development of long-term). Each CCS project will be dependent on the licensing of the person responsible for emissions. maturation projects)

Source: Author

6.5.1.3 Second path: establishing an institutional framework by law

The second option tends to improve what could not be done on institutional arrangement without legal enhancement by a bill deliberated on the Brazilian Parliament.

The main challenge is defining on the Executive branch the ministerial coordinator board, under the CCS Directive also to be settled. Many agents would act together, submitted to directive coordination, to be made in the ministerial scope, which, rationally, would be the folder responsible for coordinating actions between ministries.

In terms of executive coordination, in the PCA function, choosing one of the ministries that deal with main sectors, such as mining, energy, or industry, could be questionable since its own demands could overlay against other areas, like agriculture or general environmental themes. By reason, PCA candidates are Civil House of the Presidency of the Republic or another with a neutral position similar. They could be monitored to assess how effective have been implemented CCS rules via ministerial coordination.

Despite coordination issues, the PCA needs the technical and political capacity to coordinate sectoral conflicts, to articulate and to implement incomplete tasks that, as a result, will convert individual actions into a general system of CCS effectively.

A new legal arrangement may provide rules to order precedence RCA considering where and who will be GHG capture plants' object, reasonable penalties, and small incentives to the private sector. Consequently, it may reduce the number of agencies involved in these phases and uncertainties linked to RCA's agents' decisions.

Also, uncertainties from the sequestration stage may be reduced by pointing to a unique RCA system considering the lowest improvement required on the current institutional framework, costs rising perspective, and potential conflicts between agencies.

The leading candidates are mining and oil regulatory agencies due to legal regimes they have experienced for decades and knowledge they developed dealing with concession contracts and authorizations for using natural resources set aside geologic formations. As long as the cheapest source to be capture and stored are in the oil, the NG industry, and the biofuels, the prior candidate seems to be ANP, though conflicts caused by the overlap of concession areas in the underground water, mining and oil sector need to be solved by regulatory agencies, the Mining (ANM), Water (ANA) and ANP.

Nevertheless, it is highlighted that geologic formations available for carbon storage, as a rule, are not coincident to the targets for mining activities or underground water, especially due to the physical conditions required to keep stable the carbon dioxide in the supercritical fluid, generally deeper than 800 meters. This geological environment is not the target for aquifer for human uses.

Environmental agencies bear in mind that Union and subnational competency definitions through ordinary laws tend to judicial litigation. Hence, environmental licenses remained under the rules mentioned above.

Ongoing research indicates that the Federal Government members have a good understanding of the importance of the Paris Agreement for the climate change challenge and may impact their daily activities. Nevertheless, it would remain vague who would be responsible for strategic coordination and followed obligations derivates from COP-21 (Araujo, 2019).

Brazil ten year National Energy Expansion Plan, published by the Ministry of Mines and Energy, provides a projection for energy demands and indicates the expansion of the energy sector, under general guidelines policies, which contemplate wind, solar, biomass, or NG thermal power plants (Brasil, 2020).

However, governmental strategic planning is absent among eligible use of CCS to achieve GHG emission reduction targets. Moreover, it neglects the potential benefits of CCS projects and, thus, did not allow increment perspectives to have the energy sector as a path to deploy carbon sequestration for hard-to-abate sectors and its contribution to Brazilian NDC. Therefore, it is inferred that the energy sector portfolio has prioritized upcoming expansion through mature sources, overlooking alternative decarbonized sources even accoupled with the CCS technology.

The transport phase may define both PCA and RCA guidelines to reduce their cross-chain risks through the NG transport sector's expertise. Nevertheless, Brazilian experience demonstrate that the potential co-optation by NG distribution agents increase cross-chain and political risks, which could be fixed up by a second-best policy choice, such as establishing State-Owned Enterprise (SOE) for carbon dioxide activities or an innovative regime to this phase.

Another risk complex to reduce is long-term liability during and after the storage phase (Rassool *et al.*, 2020). Legal rules proposed via a new institutional framework for CCS may delimitate uncertainties and provide guidelines for monitoring systems, third-party audit, liability transferring process by private to the public sector, insurance, guarantees to be covered, or even a cap for costs after decommissioning of the storage site.

Alternatively, a private-public arrangement of agents may have assumed long-term liability of carbon dioxide leakage occurring after injection on the reservoir, being possible to use the SOE as a mechanism to make share costs between government and storage upstream chain, since result reducing risks and financial risk and cost of CCS projects.

Thus far, a well-defined legal framework may decrease risks via PCA and RCA, liability rules, and the CCS guidelines. Besides, it could reduce the possibility of divergent decisions or the degree of discretion of governmental agencies. On the other hand, there is effectiveness in vertical coordination activities into ministerial subjects, even if policymakers ignore the intersectoral gains. Table 6.2 provides a brief second path.

Table 6.2. *New legal system for the CCS technology, based on an ordinary bill.*

Suitability	In the Long-term, based on sectors and enhancement of institutions
Regulatory Competent Authority	ANP (priority on the whole chain), ANM (for coal), Aneel (capture on thermopower plants), ANA (underground aquifer), IBAMA or subnational environment agency (Capture on remained GHG large-scale industrial plants), SOE (complementary activities)
Political Competent Authority	Federal Executive Branch for main activities, and Subnational States Governors
Long-term Liability	Legal framework, ANP regulation, or SOE. Possibility to have judicial litigation until Supreme Court implement a case law
Remark	Political risks reduced, despite keep tendency of verticalizing on oil sector chain due to high contractual costs inter sectors.

Source: Author

6.5.1.4 Third path: constitutional reform

The third pathway refers to the possibility of constitutional changes. In this case, treatment via CF would be granted so that a single independent agency responsible for the entire CCS chain, and, at that point, may avoid PCA functions via a committee composed of several agents, and RCA might be shared only with one environmental agency. Consequently, costs and benefits could be under the competence of a single competent authority, highly specialized in CCS projects.

Therefore, as a Directive Committee would remain political guidelines under CCS legal framework and institutions related to NDC and climate change. Also, liability standards would be better defined to avoid litigation, which reduces political and long-term risks for CCS.

A monocratic authority would be established to deal with granting, legal regime, and to implement the use of the geological potential for storage of any fluid or carbon dioxide for industries in which costs make capture business impeditive due to impossibility of verticalization, remaining CCS as an interdisciplinary subject under the tutelage of a single authority. Table 6.3 provides a summary of these options.

Table 6.3. *Institutional Framework based on a single competent authority.*

Suitability	In the Long-term, dependent on the legislative process on Legislative Branch
Regulatory Competent Authority	Independent RCA and environmental authority
Political Competent Authority	Federal Executive Branch, via Directive Committee
Long-term Liability	Reduce by constitutional rules and legal guidelines
Remark	Financial risks decrease due to the institutional framework imposed via Constitution. May allow contractual costs reduction for GHG large-scale emitter industrial plants.

Source: Author

6.6 A PROSPECTIVE PROPOSAL OF AN INSTITUTIONAL FRAMEWORK

Defining competencies between agents involved in CCS activities may reduce long-term political risks and transform uncertainties along the CCS chain on business cases.

As an infant industry, CCS depends on how the legal system distributes incentives and penalties, how the arrangement of competent authorities effectively improve the technological path concerning climate change, and how to build it feasibly in terms of cash flow along with the phases of the CCS project, pondered by business risks, which means market failures of financial risks in all process steps (Havercroft, 2019; IEA, 2020a, 2019).

A diversity of monetary incentives has been used to improve CCS large-scale projects, such as tax credit, carbon tax, grant support, or SOE on high exporters countries (GCCSI, 2021). In general, they have already been established under institutional frameworks, with competent authorities pointed by governments and main guidelines known by current players. Therefore, the deployment of its projects results from the risk reduction of institutions and affordable legal incentives.

6.6.1 Governmental competence distributions between agencies: the problem of multiple players involved

A missing piece puzzle can represent the current institutional framework for CCS in Brazil.

In theory, any large-scale GHG emitters can be available for capturing its carbon dioxide. Nevertheless, incentives to cover revamp costs for adapt the current facilities to capture carbon dioxide are pretty rare or hidden on legislation. They are applicable only for elected sectors in which the primary industry can integrate CCS under the matrix of costs. The consequence is the absence of potential projects beyond the CO_2-EOR or the biofuels.

Moreover, authorization and environment license paths allow submitting a project for approval of least two agencies establish, under unhomogenized decision systems, possible disagreement between similar projects.

Concerning the sequestration phase, the private sector may have to use an adjacent legal framework to access geologic traps, such as mining or oil regimes, and then submit a CCS project to be licensed.

The effect, thus, has been an incentive to the oil industry to maintain potential on its umbrella, however, vertically integrated, per the first path and table 6.1. Under this institutional framework, the long-term process may cause an unbalanced distribution of gains to renewable fuels and the oil industry, neglecting remained GHG large-scaled emitters.

6.6.2 Empowerment proposal of a unique competent agency

Establishing a single competent authority also might represent an initial challenge for policymakers and RCA. Brazilian regulatory experience indicates regulatory agencies as a path to struggled links along the economic chain, remaining silent for those private agents that can self-regulate properly.

The recent energy framework improvements point to the ANP as a possible authority (RCA) for storage and long-term liability, supplementary by the ANM and Federal Environmental Agency. Directive Committee may be advised by governmental research agencies competent for energy studies and geologic survey (EPE and CPRM, respectively) to keep the central authority focused on critical issues for CCS business.

Capturing and transport phase may be an object of specific regulation, once risks along the chain have the potential to increase costs on its stages, and market failures have been unsolved by self-regulation of the free market, such as pollution costs and regulations patterns of free access.

Regarding CCS technology, two possible mechanisms may potentially expand upstream activities. First, minor legal incentives could help increment Internal Rate of Returns (IRR) for low-hanging fruits that have not already been in the CCS chain. In addition, establishing SOE to share costs between whole society through time, leaving a part of it with agents responsible for pollution activities.

There are benefits and disadvantages to having the public sector acting as an agent in the CCS chain. The positive point is the virtual reduction of uncertainties evolving the cross-chain risk in which the agents in the capture or storage phase use their market power to overestimate the carbon price, catching rents from the rest of the chain due to a market failure or uncertainties along the chain. The mechanism of using SOE would avoid it by virtually reducing the transport tariff (in the middle of the chain) and absorbing the long-term risks of carbon leakage post-closure to the site. The negative side is the political risk of using the SOE to other activities than the CCS business, or even the potential capture of its board and management that may increase the public expenditure and the potential corruption levels, which would make inviable the direct public intervention in the chain by public enterprises.

The most suitable path pointed is the second institutional framework (table 6.2), which could be enhanced by the potential reduction of the long-term risks in the third path (table 6.3) by changing constitutional rules defining the federative arrangement for the CCS, avoiding conflicts between the Union (Federal level) and subnational entities.

By choosing the oil agency as the RCA to the capture and transport stage, it may increase the risk of the capture agent problem once it accumulates the whole regulation chain, overweighting the importance of oil stakeholders in the CCS sector, discouraging the engagement of solely capture or transport agents.

Therefore, although possible gains, undesirable consequences can be high incentives to verticalize CCS project phases, through capture until decommissioning sequestration and long-term liabilities, focused on the oil industry.

6.7 FINAL REMARKS

The present study was undertaken to design institutional framework paths to CCS in Brazil and evaluate possible gains and costs to GHG emitters groups affected by them. The options described and analysed aim to see scenarios and extract the main factors that prevent or help CCS implementation as a mechanism for reducing CO_2 emissions on large-scale industrial plants.

It has been proposed three complementary paths to design the CCS institutional framework.

Under the current institutional framework, the first path has been modelled, showing that multiple competent agencies must be fulfilled. However, they can have a divergent interest, resulting in a strong barrier for CCS projects related to other sources than biofuels and NG processing plants.

The second path aimed to remove key barriers and to allow adding major emitters facilities adjacent to the oil industry or biofuels, under the verticalized chain, remaining GHG hard to reduce manufactures out of the solution, such as steel, cement e chemical manufacturing, unless they were able to do a partnership with major oil companies, proposing using the SOE as a mechanism to reduce and distribute and gains through CCS chain and the entire life cycle of the CCS project.

The third path increment aimed to reduce litigation and long-term liability due to uncertainties of carbon dioxide leakage from storage site and federative conflicts between Union, State members, and its related agencies.

The analysis supports the idea that competent authority for CCS may evolve more than one agency in terms of regulatory duties and the hierarchical coordination of high-level policies. However, reasonable criteria indicate that using incremental steps by sector can help agents better understand how private agents respond to Brazil's institutional changes.

It is also essential to focus on implementing the CCS from the definition of the composition of agents involved and the division of responsibilities between them and propose mechanisms for structural reduction of the activity's risk.

Among them is the problem of the regulatory capture of the oil agency, which makes it hard to engage agents interested in developing transport pipelines or dedicated capture facilities out of oil agency scope solely. Therefore, once activities concentrate in this bureau, rules, and mechanisms for dealing with the problem presented figure are essential for the success of the CCS in the sectors adjacent to the energy industry.

The institution of an SOE must consider the frameworks of governance and best practices of public expenditure to avoid politicians' misappropriation of the budget or decision process. In addition, the SCO, such as Petrobras and Equinor, cannot apply cash flow available freely in low-profit assets. This behavior implies the need for legal enhancement, public regulation, or intervention to make a private activity developed by the SCO, as profit as necessary to justify to the board the company's engagement in the CCS business.

The CCS institutional framework must consider the political context of governmental changes and decision-makers' commitment. Nevertheless, the reasonable competent authority system under the institutional framework is essential to improve CCS and allow net-zero carbon dioxide emission as a role.

The question raised by this study is how these factors change over time and how to reshape institutions to maintain positive effects on climate change mitigation policies.

6.8 CHAPTER 6 REFERENCES

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7 INSTITUTIONAL ASSESSMENT AND THE ECONOMIC INCENTIVES FOR THE CCS BUSINESS IN BRAZIL

7.1 INTRODUCTION

Over the last fifty years, human activity post-industrial economy has become the object on climate agenda evolving natural processes changing over the environments, its influences on biodiversity and conservation requirements (IPCC, 2014c). After COP-21 and the new wave of commitment to climate issues by several countries, the net-zero target came back to the political agenda on the GHG emitters countries (House, 2021; IEA, 2020b; Locatelli and Sainati, 2016; Varro and Fenquan, 2020). Those political pledges have induced the previous assessments of mitigation measure options, including the carbon storage technology and clean energy, even though immediate concrete effects on Greenhouse Gas Removal (GGR) by engaged countries was minor (Kapetaki *et al.*, 2016; Mac Dowell and Staffell, 2016; Rassool *et al.*, 2020).

Establishing legal and institutional frameworks under each country's jurisdiction has been a critical concern for the decision-makers. They tried to transpose GHG emission for main sectors and their previous efforts to tackle the climate issue into action that could distribute responsibilities more efficiently, benefits, costs allocation along business chains, and, more recently, consider the financial assessment, fiscal allocation, and policy enhancement by governmental decisions (Averchenkova *et al.*, 2021; Barr *et al.*, 2010; Campiglio *et al.*, 2018; Scott, 2008). For that, they ponder exogenous components' interference on the political process, harmonizing the environmental concerns and the goods' provision to society for GHG emitter businesses (and thus deliver gains).

The role process of building legal framework has to be done for carbon capture, transport, and storage technology (CCS) uses on leading economies, which evolves establish comprehensive legal and regulatory frameworks to shape policy instruments available and create positive interactions with each other resulted from the "smart regulation" of the policy mix, such as these categories: organizations – bureaucracies –, authority – political and regulatory –, and information – public acceptances and public participation (Howlett and Rayner, 2007; Osazuwa-Peters and Hurlbert, 2020),

Beyond that, incentives provided by public treasures or by law have the potential to accelerate the new CCS business developments under the low carbon economy, even though it remains incomplete other public policies categories that regulate safety storage, long-term liability, and rules to access favourable geological formations (Narita and Klepper, 2016; Osazuwa-Peters and Hurlbert, 2020).

The previous literature review demonstrates the public support and the consistent financial mechanism needs to move forward carbon sequestration projects, such as the Norway institutional rules that implemented the enhanced and just fiscal rules using a carbon tax to make the CCS projects feasible (Bruvoll and Larsen, 2004; Ogihara, 2018). They debate how the carbon pricing process could shape consumers and change them for a low carbon economy using regulations, command and control rules, minimum standards for emissions, fiscal policies, carbon clubs, carbon markets, and international schemes related to tackling financing barriers (Agerup, 2016; Baranzini *et al.*, 2017; Hongo, 2018). It is possible to infer that the incomplete framework for CCS technology has shaped institutional changes in key countries since policy instruments have provided conditions to positive cost-benefits ratio.

Despite that, fewer studies have investigated the importance of financing mechanisms or schemes for technologies applied to low carbon transition in developing countries or how they articulate fragmented frameworks used by hard-to-abate sectors to promote a new low carbon economy, and the developing economies have been neglected by the institutional assessment considering the incentives for CCS, the CO_2-EOR deployment, BECCS, or permanent carbon sequestration in selected sectors, even having legal gaps and endogenous uncertainties unsolved (Araújo *et al.*, 2021; Cai and Aoyama, 2018; Li *et al.*, 2021; Sanderink, 2020; Yu and Zhu, 2015).

Considering the CCS business needs to booster from an infant industry to a real climate change contributor, this paper aims to discuss the incentives and the institutional changes that can induce CCS large-scale projects based on ancillary activities of energy sectors and their legal frameworks.

For that, we segmented into two major sections. The first section presents a brief overview of Brazilian commitment to climate change and the legal and institutional settings that allow deducing the CCS incentives for implementing BECCS projects into Renovabio's policy; for Brazilian EOR incentives as a supporter for carbon storage in mature fields; and for incorporating CCS into petroleum legal framework and its agreements to reduce long-term liability uncertainties. The second part presents prospective incentives that may booster Brazilian CCS projects embracing base industries and critical legal gaps. In conclusion, it aims to diagnose those changes and how it influences agents' behaviour for engaging GGR targets.

7.2 METHODS AND PROCEDURES

The main hypothesis proposes that the CCS large-scale projects in Brazil could be implemented using current incentives for adjacent activities related to critical sectors. The secondary hypothesis indicates that punctual changes can establish favourable conditions to deal with the long-term uncertainties of carbon sequestration.

In order to identify hidden incentives for carbon sequestration, we have chosen the energy sector as the most suitable to implement the CCS business through the current legal framework. The criteria for selection were picking up legal schemes that may add value for the main business via carbon sequestration. Their mechanisms may reduce the government's fiscal share in the oil industry, concede carbon credits in the biofuel sector, pay for environmental benefits in the electricity generation, and mitigate long-term liability for carbon leakage.

Based on significant economies' experience, we have proposed new incentives for the long-term liability in the Brazilian framework and the transport phase, linking capture systems to storage sites, and then to the success of CCS in a low carbon economy scenario.

Specifically, the energy lock-in system may cause bias for the analysis due to the tendency to overvalue oil industries' experience and ignored disruptive scenarios. Further research would be necessary to deal with energy transition in imperfect legal and institutional frameworks.

7.3 THE CCS BUSINESS AND THE INTERNATIONAL CLIMATE COMMITMENT UNDER THE FRAGMENTED INSTITUTIONAL FRAMEWORK IN BRAZIL

The Brazilian commitment to climate change took place via legal changes, via a State-Controlled Enterprise, Petrobras, as an interventional instrument in the economy, and via fighting against illegal deforestation to achieve the GGR near-term (MMA, 2018). Nevertheless, those split actions could not imply substantial future efforts to achieve the Paris Agreement 2º C limit due to the current high renewable share of the energy market, the cultural habits of consuming biofuels, and the Brazilian technological strategy, in which the CCS remains considered unlikely to wide deployment by 2030 due to the absence of precise regulation and incentives (Carvalho *et al.*, 2020).

Thus far, previous studies provided information about the Brazilian legal systems, the possible arrangement among high GHG emitters and its commitment, and climate change in a broad view (Jose Ricardo Lemes de Almeida *et al.*, 2017; Costa and Musarra, 2020; Costa *et al.*, 2018; Morbach *et al.*, 2020b; Moreira *et al.*, 2016; Rochedo *et al.*, 2016; Romeiro, 2014). They considered the absence of the whole CCS legal framework might represent a problem to be tackled and overwhelmed. The recent issues have focused on Brazilian CCS technology policies analysis.

Besides legal gaps, in implementing any public policy, the market agents tend to follow national policies' main guidelines to request governmental empowerment better and improve return rates. It means the absence of incentives directly applied for the CCS large-scale projects could reduce the private sector's encouragement to invest in the CCS business. Despite that, punctual routes into energy policy mature institutions reveal a hot spot for it, for example, by using other sector's guides and business, out of Brazilian *i*NDC and its climate change commitment, to develop CCS projects.

7.4 CURRENT INCENTIVES FOR THE NEW CCS BUSINESS IN THE ENERGY AND CLIMATE POLICIES IN BRAZIL

As regards the government decision’s effects, literature allows inferring that the institutional model aimed to reduce it through behavioural induction of agents and its relationship between the legal framework and economic consequences when the transaction costs cannot be reduced to zero (Coase, 1937; Posner and Calabresi, 1970; Williamson, 1979).

Brazilian climate change policy has been acquiescent on establishing direct incentives to CCS project as a mix of solutions to tackle GHG emission abatement and its NDC targets. Despite that, the current incentives to traditional polluter industries can result in tangent encouragement to the carbon dioxide sequestration activity (MMA, 2018; MME and EPE, 2021).

Under the transport sector, the mandatory blend of biofuels in diesel and gas are the main rules, followed by the fees and tax reduction for renewable energy in contrast to the substitute fossil fuels and funding for undertaking bottlenecks. For that reason, the BNDES provided funding for biodiesel facilities and offseason ethanol storage. Main costs are passed to consumers' prices or Brazilian Treasure. RenovaBio intensifies these systems of biofuel and could let CCS business improve through it.

The oil industry has been using taxation reduction as a mechanism to deploy oil production. Institutions have been shaped since the Brazilian petroleum monopoly ends, which build a favourable contractual arrangement for concession regime and the arbitration system to prevent the private sector of political waves that floats between interventionism and liberalism (Araújo *et al.*, 2019).

In addition, EOR in mature fields becomes a priority on the regulatory agenda to implement the hydrocarbon rational exploitation. Both cases can be used to reduce costs or to improve the CCS projects' cash flow.

7.4.1 Renovabio and BECCS

The biofuels industry plays a vital role in Brazil's energy system and presents opportunities to achieving negative emissions based on CCS.

Building on a centuries-old sugarcane farming activity and technological and political developments of the 20th century, biofuels production and utilization in the country have its milestone, the *Proalcool Program* (Bennertz and Rip, 2018; Rodríguez-Morales, 2018). It was implemented following the first oil crisis of the 1970s and strengthened by the second. The program relied on a mandatory blending of sugarcane ethanol to gasoline and the later introduction of 100% ethanol-fuelled light-duty vehicles to replace a share of the imported oil products. Since then, periods of convergence and conflict between the government interests and the sugarcane industry marked a series of booms and crises of the sector (Bennertz and Rip, 2018; Rodríguez-Morales, 2018).

In 2003, flex-fuel vehicles – running on any mixture of ethanol and gasohol – came to the marketplace. In three years after, they already embodied more than 80% of new licensed cars in Brazil. In 2019, flex-fuel vehicles represented 94% of the total 2.3 million new cars registered (Anfavea, 2019).

Due to the well-developed biofuels distribution and commercialization infrastructures that make both hydrated ethanol (sold as E-100) and gasohol (with a current maximum of 27% anhydrous ethanol blend) available at fuel stations, this system put on consumers hands the choice of what fuel they could choose, helps stabilize price fluctuations, and increases the supply security nationally.

Running on both sides, as a complementary fuel and as a competitor to gasoline, the sugarcane-ethanol has been incentivized primarily by the mandatory blend and by the fuel tax differentiations at the federal and the state levels. Table 7.1 illustrates ethanol's share in the Otto cycle fuels and the energy mix of 2019.

This corresponds to 35.7 million litters of ethanol, of which 95.3% was produced from sugarcane and the rest from corn (CONAB, 2020). Still a small but promising industry in the country based on feedstock availability.

Table 7.1. *Brazil's Otto cycle fuels (energy supply' share in 2019).*

Fuel	Market share (Mtoe)
Natural gas	5% (2.05)
Gasoline	52% (21.32)
Anhydrous ethanol blended with gasoline	14% (5.74)
Ethanol hydrated (E100)	29% (11.89)

Source: EPE (2020).

Nevertheless, in a recent period, gasoline prices were arguably kept artificially low by the Brazilian SOE Petrobras while oil prices skyrocketed. This circumstance has pushed the issue to the political arena to promote measures supported mainly by the sugarcane industry to reduce the indirect government's control of the domestic fuel market and adopt a market-based policy to internalize biofuel's GGR externality.

The new Brazilian Biofuels Policy – RenovaBio – was approved in 2017 and fully implemented in 2020. With a similar design to California's Low Carbon Fuel Standard (LCFS), RenovaBio uses the lifecycle GHG emissions assessment of biofuels to award producers and importers decarbonization credits (CBIOs, corresponding to 1 ton of CO_2 equivalent avoided). In turn, 10-year national fuel supply decarbonization targets are published annually and converted into CBIOs purchasing requirements by fuel distributors. This structure creates a supply and a demand for CBIOs, developed an environmental stock market to reduce transaction costs, and provides transparency for the CBIOs trading. Ultimately, the policy developed a carbon price signal for incentivizing low carbon biofuels production, including ethanol, biomethane, and biodiesel – which currently has a 10% mandatory blend to diesel and a 13% cap.

The lifecycle GHG assessment is performed using a government-provided calculator named RenovaCalc[25] (Matsuura *et al.*, 2018). The assessment is individual, i.e., each biofuel producer uses their real data as inputs to the calculator[26], and includes the phases of agriculture, industrial process, and transport of biofuel produced. In terms of their average impact on ethanol emissions, the inputs that can be highlighted are the use of soil pH correctors, synthetic fertilizers, and diesel in harvesting machinery and for biomass transportation to processing plants (Matsuura *et al.*, 2018).

As the methodology allocates emissions to the plant's products, sugar production and electricity generation from sugarcane residues reduce ethanol's emissions. The result provided by the calculator is the carbon intensity (CI) of the biofuel produced in grams of CO_2 equivalent per megajoule (gCO_2e/MJ). Then, the biofuel's CI is compared to a fixed CI of a reference fossil fuel.[27]. The result is the CI difference, i.e., the emissions reduction per megajoule of each biofuel. That number can then be multiplied by the volume of the biofuel[28] sold. This results in the total amount of emissions avoided by that producer[29], which is finally converted to CBIOs. As presented in Table 7.1, 221 ethanol plants were certified under RenovaBio as of February 2021.

There are many GGR opportunities in the average ethanol production process, such as using advanced agricultural techniques to reduce inputs, increasing

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[25] The methodology uses a well-to-wheels approach. It was developed based on ISO standards applying the ecoinvent v.3.1 database.
[26] The process must be certified by a company accredited by fuel's regulator ANP
[27] The comparison depends on the biofuel's end-use. It directly compares the Otto cycle (ethanol to gasoline) and Diesel cycle-fuels (biodiesel to diesel from crude oil).
[28] Converted to energy according to the biofuel's lower calorific value.
[29] Compared to the counterfactual of the energy being supplied by the reference fossil fuel

efficiencies in the lifecycle, and making use of residues for energy production (direct combustion for electricity, conversion to biogas for electricity or biomethane, and using lignocellulosic material to produce second-generation ethanol).

It is also well-known that sugar fermentation for ethanol production in sugarcane mills generates a considerably amount of pure CO_2 stream seasonally, providing an opportunity for BECCS. However, this option is not yet contemplated in the CI calculation methodology. In a few cases, the CO_2 is already used for supplying other industries in Brazil, while in the United States one corn ethanol plant has successfully implemented a large-scale CCS project with dedicated storage, and four more North American plants have small-scale capture coupled with EOR (Consoli, 2019). Based on simple stoichiometry[30], the complete fermentation CO_2 capture estimate corresponds to the potential reduction of 36.2 gCO_2e/MJ if all avoided emissions are allocated to the produced ethanol. Therefore, based on the current average CI of RenovaBio, as shown in the Table 7.2, the CCS could make the average ethanol produced in Brazil carbon negative.

The total potential available for CO_2 capture from the fermentation process in ethanol plants in Brazil at 27.3 million of metric-tons of CO_2, matching a literature estimate of 27.7 million tons (Moreira *et al.*, 2016). Furthermore, CO_2 capture from bagasse combustion in boilers for steam generation could be an additional source to increase carbon availability and the project's scale, which could reduce unitary costs. However, this emission source requires a process for selectively capturing CO_2 to purify and make it storable.

In terms of costs, the CCS technology in the ethanol plants have been assessed at US\$ 30.3/tCO_2 (Moreira *et al.*, 2016), while others estimated costs at US\$ 50.8/tCO_2 for a reference case and US\$ 39.4/tCO_2 for larger plants (Restrepo-Valencia and Walter, 2019). By integrating ethanol distilleries with fossil-fuel processing plants in optimum carbon capture and transport network, it is possible to tackle the challenge of the seasonality of carbon production from sugarcane ethanol and the firm load in

[30] The fermentation reaction is $C_6H_{12}O_6 \rightarrow 2\ C_2H_5O + 2\ CO_2$, and the molar masses are 46.07 g/mole for CO_2 and 44.01 g/mole for ethanol. The lower calorific value for ethanol is 26.4 MJ/kg. For total CO_2 capture potential in the ethanol industry, we considered the production of 35.7 billion litters of ethanol in 2019 (CONAB, 2020) and ethanol's specific mass of 0.8 ton/m^3.

the pipeline, having an average levelized cost of transport of a levelized 26 US$/t$CO_2$ (Tagomori *et al.*, 2018). Through a cluster system from ethanol distilleries inland CO_2-source to the CO_2-EOR in the Campos offshore basin fields, the best and worst scenarios ranged between 32 and 87 US$/t of CO_2 (da Silva *et al.*, 2018a). Therefore, it is notable that current CBIO prices, shown in Figure 7.1, these costs remain relatively high.

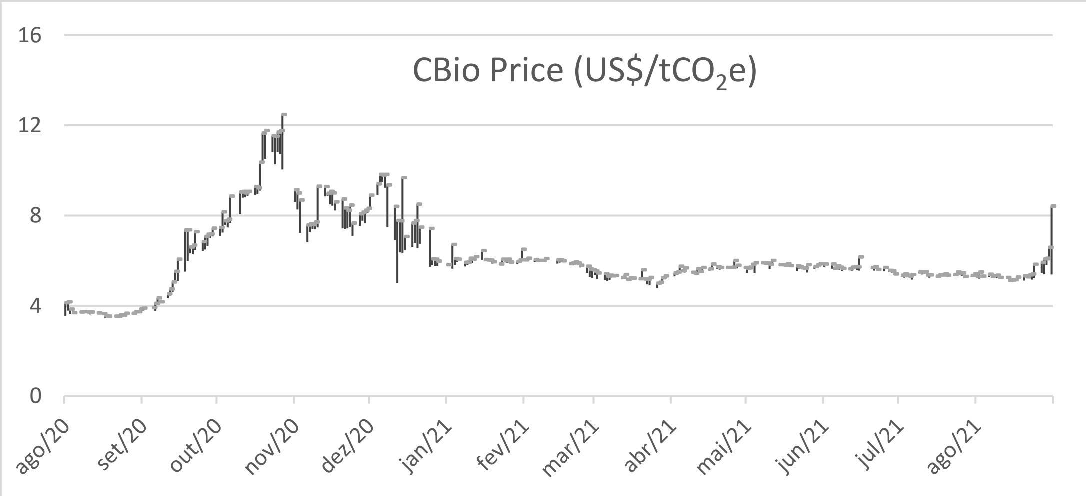
Table 7.2. *Average carbon intensity (CI) of biofuels under the RenovaBio policy (ANP). Note: 1G – First Generation; 2G – Second Generation (lignocellulosic). The negative emission for ethanol considered only CO_2 captured from the fermentation process.*

Fuel	Number of certified plants	Average CI (a)	(a)+BECCS	Reference fossil fuel (CI)	Reduction intensity
		in gCO_2e/MJ			
Ethanol 1G – Sugarcane	216	27.8	-8,4	Gasoline (87.4)	59.6
Ethanol 1G+2G – Sugarcane	1	26.7	-9,5	Gasoline (87.4)	60.7
Ethanol 1G – Sugarcane + Corn	3	25.2	-11,0	Gasoline (87.4)	62.2
Ethanol 1G – Corn	1	16.7	-19,5	Gasoline (87.4)	70.7
Biodiesel[31]	23	15.8		Diesel (86.5)	70.7
Biomethane	1	5.9		Average: Gasoline, Diesel, Natural Gas (86.8)	80.9

Source: ANP

[31] It is important to highlight that the indirect Land Use Change (i-LUC) have not been accounted properly for carbon intensity calc, which can bias the assessment of biodiesel´ CI.

Figure 7.1. *RenovaBio's decarbonization credit (CBIO) prices from August 2020 to September 2021*



Source: B3 (2021).

Although the CI calculation methodology has not yet incorporated CCS, the policy's legal framework, in Article 28, has included providing a 20% bonus for every biofuel producer that certifies its product to negative lifecycle emissions. Therefore, implementing BECCS in the sugarcane industry could increase the CBIOs the producer receives in two ways. First, by reducing the CI and increasing the emissions reduction intensity, and by potentially leading ethanol to negative emissions and generating 20% extra CBIOs for the producer.

The potential incentive could be financing CCS through renewable energy funding expertise. For instance, recently, BNDES developed a specific credit for financing projects that help biofuel producers reduce lifecycle emissions. The bank has announced that 1 billion Brazilian Reais (nearly 190 million dollars[32]) are available until 2022. Then, BECCS development could benefit from its national grant funding, with favourable economic conditions.

Therefore, RenovaBio creates a carbon pricing system for biofuels in Brazil, dominated by sugarcane ethanol. Fermentation produces a pure, low-cost CO_2

[32] Considering exchange rate BRL-USD of 27th Jan 2021, from Brazilian Central Bank. Available at https://www.bcb.gov.br/estabilidadefinanceira/historicocotacoes Accessed at 25 Jun. 2021.

source in its processing plants, considered low-hanging fruit for BECCS. Also, the policy included a 20% bonus for negative emission biofuels. However, current price levels are still relatively low, although they could eventually increase as the policy matures and targets become more ambitious. Hence, today, only attached with other monetization solutions BECCS can be viable, such as using carbon dioxide to EOR on depleted fields not far from ethanol plants. In addition, Brazil presents a usual risk of fuels price-controlled by the government, which affects the competitiveness of ethanol and the CBIO´s price (Hallack *et al.*, 2020).

The CBIO does not result directly in a compensating system of carbon emissions. The ordinary CBIO represents an outcome of ethanol trade in the Brazilian market, different from decarbonization process such as occur from reforestation, then, it does offset carbon globally, but an only certificate that generated carbon emission happen within a renewable cycle that avoids emission from gasoline via ethanol consumption as a substitute good. The CBIO from BECCS, on the other hand, would represent a negative emission that may compensate other emitting sources beyond the carbon zero-fuel emission of the ethanol as a good.

In July 2021, Brazilian infrastructure reached 17 corn-based ethanol plants, and a large-scale project has been announced using BECCS. The Fuel Sustainability Bioenergy (FS), a joint venture between the Tapajós Participações S.A. (previously Fiagril) and the Summit Agricultural Group, plans to implement carbon dioxide capture from its fermentation process, dehydrating, compressing, and storage near its mills 5km distance[33].

The suitable area for FS BECCS project is the Parecis Sedimentary Basin, that, in terms of geology assessment, its geological reservoirs figures feasible for permanent storage, once the basal carbonate level can reach up to 5.6 km of depth, and the negative Bouguer anomaly indicates an FS site adjacent, in the southeast portion of the Juruena Sub-basin, that could have geological targets to be prospected (Haeser *et al.*, 2014). Even with that, it needs to attend the following steps to understand better the basin CCS potential and the institutional viability of the proposal.

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[33] Available at https://bioenergyinternational.com/biofuels-oils/fs-plans-south-americas-first-beccs-project-at-fs-lucas-do-rio-verde-in-brazil. Access: 25 Jun. 2021.

Nevertheless, this project represents the first BECCS initiative in Latin America, and it is located outside the leading industrial clusters.

7.4.2 EOR in mature fields

The EOR methods have been used worldwide for many decades to deal with the need for oil demand and its crisis. To define the most suitable method for each field, it has to consider the hydrocarbon properties, such as API Gravity, viscosity, and composition, and the reservoir characteristics – Oil saturation, geologic formation hosting the oil field, net thickness, depth, and temperature (Joseph J. Taber *et al.*, 1997).

From all possible arrangements, such as screening criteria previously developed, data analysis pointed the thermal and the flooding gas EOR's methods have to lead as meaningful choices, primarily applied in the onshore environment (Ferreira, 2016; Kang *et al.*, 2016; Joseph J. Taber *et al.*, 1997).

The election of the EOR method depends on more than reservoir and oil characters. In the offshore basins, the hydrocarbon fields in which the EOR methods are eligible must observe other variety than onshore projects, such as feasible resources, infrastructure costs, and supply conditions that could affect the decision of a recovery method. In deep water, the distance between production wells involves the modelling of fluid flow and may turn challenging to measure EOR results. In addition, offshore facilities have constraints of space and weight considering equipment needed in the production platform to implement the fluid injection and management to increase oil recovery, as well as environmental concerns on formation water releases or its treatment (Ferreira, 2016).

The method CO_2-EOR flooding is based on the injection of large quantities of carbon dioxide into the reservoir to extract the light-to-intermediate components of the oil, and, if the pressure keeps high, the hydrocarbon displacement is favoured due to miscibility developed (J J Taber *et al.*, 1997; Joseph J. Taber *et al.*, 1997). This method is indicated to sandstone or carbonate as reservoir geologic formation, hydrocarbon in which viscosity is less than 10 cP and the gravity is at least 22 ºAPI in a field deeper than 1220 meters (J J Taber *et al.*, 1997). Even though technical constraints could reduce suitable oil fields, a significant barrier have been the carbon dioxide supply in low-cost bases, which make the natural gas produced locally in each oil field the most suitable source for offshore EOR (Kang *et al.*, 2016). For instance, they represent a second-best choice case considering carbon dioxide performance when available (Liu *et al.*, 2020).

Governmental decisions focusing on current mature production oil fields could shape the Brazilian industry once they have approximately 200 hydrocarbon fields been exploited for more than 28 years, with its production fallen considerably in the last decade. The regulatory agency pointed out that the recovery factor for the *offshore* production achieved 24%, far below than observed on North Sea Basin (ANP, 2017). Despite the methodology difference indicating that recovery factors of both basins are not directly comparable, it is possible to highlight the opportunity to increment hydrocarbon production in the mature Brazilian fields. As a driver to implementing public policy, the CNPE approved the Administrative Rule nº 17, of 2017, providing a new directive and guidelines to the energy policy.

After the end of the oil monopoly in Brazil, with the Law n. 9478, of 1997, the E&P activities have been developed under contracts celebrated between operators and Union, and it has established a time extension option. Complementary directives have recently been approved through the Administrative Rule nº 6, of 2020, enabling the operator's choice to extend concession contracts up to 27 years, whether hydrocarbon oil fields production was viable. As a condition, it would require a new investment plan to manage natural resources better and avoid predatory exploitation. Counterbalancing the need for new investments for EOR, it will be possible to pledge a producing-based royalty reduction in the incremental production, from 10% to up to 5%, which means that oil and natural gas from EOR technology in mature fields will have a competitive government take. Then, a secondary consequence of the new directive, and the prospective condition of around 200 mature fields and its less than 30% recovery factor could work as an indirect incentive to develop CCS through CO_2-EOR in the oil field (Loureiro, 2017).

Even before the new rules, expertise in the EOR has been developed by Petrobras. The main large-scaled EOR in Brazil was steam and hot water injections since the late '70s in many onshore fields producing heavy crude oils (Rosa and Machado, 2017). They have also used in-situ combustion, desalinated water injection, and polymer flooding to maintain the field's pressure or control water's production. The SOE has used CO_2-EOR in sandstone in three *onshore* oil fields in the Recôncavo-Tucano-Jatobá Rift Basin. However, they achieved success only in the Buracica oil field (Dino and Gallo, 2009; Estublier *et al.*, 2011; Rosa and Machado, 2017). The Miranga field has figured as the potential CCS-EOR from anthropogenic sources (Dino and Gallo, 2009). However, due to the high price of CO_2 source, or difficulties of gas supply assurance, it has been abandoned (ANP, 2017).

Despite the incentive, an operator that pledges royalties' discount can submit a more convenient method for EOR considering only fiscal return and financial return. The mature oil field Polvo, the first approved under this mechanism, predict to extend its lifetime in ten years by using other than CO_2-EOR due to resources and methods available and the costs to implement it (ANP, 2020).

The main question is to know the mature fields more suitable for CO_2-EOR in the Brazilian oil basins and provide a stable offer of carbon supply. For that, the mature onshore basins remained as candidates, and the offshore cluster in which the oil fields present technical features favourable for EOR miscible methods using carbon dioxide and the carbon hubs that may provide anthropogenic carbon dioxide (da Silva *et al.*, 2018b; Ferreira, 2016; Tagomori *et al.*, 2018).

In summary, fiscal incentives based on tax and royalty's deduction (production-based) may represent robust enforcement to the CCS by way of ancillary oil activity, once the large-scale oil fields have a low cost of capture and transport of CO_2 (low hanging fruit), an incremental oil production supporting the cash flow needed, the low cost in terms of investment due to depreciated costs of mature fields and its infrastructure, and the favourable tax system for new investments. Nevertheless, institutional changes remain incomplete concerning the minor target of GHG reduction. Fiscal incentives via royalty reduction did not differentiate the recovery method submitted under development mature field plans.

7.4.3 Incentives for the CCS from the oil industry's framework

The Brazilian oil industry has a tax credit system that allows 'cost's deduction of corporate income tax to be paid for expenditure on exploration and development phase (deployment) of oil fields under concession, production share agreement (PSA) or right agreements transfers. Brazilian incentives framework also allows accelerated exhaustion of investments necessary to make viable oil and natural gas production. The general effect is a considerable government take's reduction into oil rent and its consequent attractively framework to the oil industry.

Fiscal incentives first appear after the conception of the Brazilian SOE, Petrobras. In 1966, the income legislation allowed the company a tax deduction based on expenditure on prospection and crude oil extraction annually.

After the petroleum monopoly ends, the legal framework has been acquiescent about a possible extension of these fiscal benefits to other oil companies, which resulted in litigation and judicial decision favourable to private operators. More recently, lawmakers have approved a reform and consolidate the ancient system of fiscal deduction incentives (Furtado *et al.*, 2019; KPMG, 2018).

As a regulatory requirement, governmental agencies enforce emissions patterns that do not fit on ventilation, as a rule, raising the need for CO_2 storage near the oil field. In general, oil production facilities have appropriate processing plants for natural gas segregation on hydrocarbon fractions and other components, such as carbon dioxide, and it results in a pure GHG fraction previously ventilated to the atmosphere. Bearing in mind that CCS activity may work as an ancillary stage into oil extraction, the same fiscal system could be applied to deploy carbon sequestration, which is already counted as Capex and Opex into the oil field development plan.

An example is the pre-salt cluster, representing a significant opportunity for the oil industry and CCS project in Brazil. The Campos and Santos Basins have word-class oil fields; both show a high carbon dioxide-natural gas ratio (D’Almeida *et* *al.*, 2018). Currently, Lula and Sapinhoá oil fields represent the first offshore large-scale CCS project (GCCSI, 2021).

The consortium has decided strategically not to vent to residual atmosphere gas produced by offshore processing plants, considering regulatory and environmental license requirements as a condition to operating. The production system adopted injection wells to discharge (alternating water gas – WAG) (Rosa and Machado, 2017). Then, considering the CO_2 storage implementing process represents a share of oil's business, fiscal incentives can be equally applied on facilities needed.

Thus, the CCS activities have an indirect fiscal incentive under the Brazilian petroleum framework that allows recovery investment costs through accelerated exhaustion and reduction income tax due to oil companies.

7.4.4 Environmental benefits in the electricity legal and regulatory frameworks

The electricity legal framework in Brazil has been progressively enhanced through the last decades to induce a free market and promote the privatization of public utilities and main public energy assets. Like other international players, Brazil established subsidies for alternative renewable energies, mainly wind, biomass, and solar.

More recently, lawmakers enhanced the rules to change a current harmful incentive for a rational guideline to recompense outcomes from clean energy generation. The new legislation, the Law n. 14.120, of 2021[34], delegate to the Executive Branch the power to:

[34] Available at http://www.planalto.gov.br/ccivil_03/_ato2019-2022/2021/Lei/L14120.htm. Accessed at 25 Jun. 2021.

i. *define guidelines to implement, in the electricity sector, a mechanism to consider environmental benefits, in line with the mechanisms to ensure supply security and competitiveness in the following twelve months after the law entered in force; and*

ii. *provide a mechanism to the possible future integration between its benefits and other sectors, joining to ministries involved.*

The first goal of its mechanism was to adequate the level of subsiding conceded for wind, solar, biomass, and small hydropower plants due to the tendency to capture available financing sources by modular plants, such as solar and wind cheapest among them. Moreover, the benefits represented a perverse instrument for transferring income from many small regulated consumers to a small group of agents with powerplants (Silva, 2015).

For the CCS, the legal instrument can be modelled to induce the capture phase for NGPP or other fossil fuel facilities, balancing the costs involved in this process and the consequent transport and storage costs and the assurance needed for long-term liability.

In 2020, fossil fuel produced 45% of the total electricity consumed by the Brazilian market, being 22.8% from coal, 11.8% from oil, and 11.6% from natural gas (EPE, 2021). The sectorial planning indicates expansion via the flexible thermopower plant (12.3 GW), wind (11.8 GW), solar (3.6 GW), hydropower (5.8 GW), and an incipient share for coal modernization (MME and EPE, 2021).

The important issue is that flexible thermopower plants are not suitable for capture, which may represent a negative point to the expansion of the natural gas as a source of electricity, then, the governmental planning does have to see properly how they would address the capture in this chain.

To implement the CCS business through secondary sectors, a path for policymakers to design electricity auctions for retrofitting fossil fuel thermopower plants, such as NGCC near industrial clusters and storage sites working dedicated along the year.

This mechanism of auctions, however, would represent another market failure, once they may reduce the number of participants elected in the current generators, and they may increase electric tariff, impacting regressively the consumers. In order to mitigate potential negative awareness and rationalize incentives, only a share of the total thermopower plants could be capable of winning the auction, which induces the competitive process to reduce the capped tariff used to model the result projected.

Therefore, keeping the attention of the total impact in the tariff, the competitiveness in the selected group of fossil fuel plants, and the spillover effect around industrial clusters, the CCS electricity auction may have success to increment the GGR in the Brazilian energy and manufacturing sectors.

Once the Executive Branch decides to implement the environmental benefit for electricity, the capture phase can be eligible to use the incentive to decarbonize current facilities and the indicative capacity expansion.

The benefit cap to be considered will probably not be sufficient to cover all costs of the CCS business; therefore, the inclusion of other GHG industrial sectors as a complementary scheme could be necessary for funding adequately the whole chain. Summarising table 7.3 presents the key aspects of the current incentives for the CCS Business in Brazil.

Table 7.3. *Current incentives for the CCS business in Brazil.*

Incentives	Main activity	Strengths	Weaknesses	Opportunities	Threats
BECCS	Biofuels and Electricity	Reduced costs for Capture[35]	High cross-chain risk, and difficulties to transport and store CO_2	Carbon market international trade, and CO_2 supplier for oil industry	Business risks Infant industry Complexity of energy transition
CO_2-EOR in mature fields	Oil industry	Monetization process well-known by agents	Lack of CO_2 suppliers, and of specific incentives for CCS-EOR	Reshape institutions, agents' engagement, and promoting regional development	Cross-chain risks
Oil industry's framework	Oil industry	Stable institutions	Restricted to vertical integration in the oil industry	Using agreements as anchor for long-term liability	Possible judicial changes
Environment al benefits	Electricity	Provide reliable carbon pricing scheme	Untested. Resistance to input costs for consumers	Allows CO_2 capture in the inflexible thermopower plants[36]	Competition between energy sources to take its budget

Source: author

7.5 POTENTIAL INCENTIVES

Minor legal improvements can result in significant gains in the CCS business. The possible arrangements for dealing with project constraints may focus on two parts: solving hard-to-reduce risks and sectorial market failures. From the first group, corresponding to the component that mitigation measure can partially undertake its barriers related to policy, revenue, cross-chain, and long-term storage liability risks (Zapantis *et al.*, 2019), while the second set aggregate the complexity to link the diversity of industrial capture sources and its costs to the consecutive phases and then

[35] This strength is available only for the ethanol fermentation or biomethane reform. In the bagasse fired-thermo power plants, the capture process does not represent a low-hanging fruit and remain being an issue to the R&D and the industry.
[36] If the power plants are used as flexible plants, it could compromise the capture process, unless there is a purge for the capture plant allowing not using it in the case of fast ramp-ups, which is currently not compatible with them.

sharing revenue and risks with transport, storage and long-term liability on the permanent storage phase to the CCS agents.

The hard-to-reduce risks cannot be directly associated with technological challenges. The CCS technological development follows a concomitant and synergic pathway to the legal and regulatory frameworks. As long as they become reliable, they produce mechanisms for allowing lawmakers and policymakers to adopt stimulus for making a business-friendly environment, reducing the perception of long-term risks associated with the CCS uncertainties. Consequently, higher interest rates from default orthodoxy loans can be exchanged for the lower and more competitive interest for the engaged agents (Zapantis *et al.*, 2019). The prospective sectorial incentives may target levelling mechanisms to artificially reduce the current cost for capturing carbon dioxide, considering the possible acceptable cost in a low carbon economy and the inflation that it can cause. Then, the learning-by-doing scheme by incremental policy changes may be implemented by policymakers.

In the developing countries' institutional principles, fewer potential near-term suggestions can be achieved to reduce transactional costs, uncertainties and then de-risk CCS projects. Considering the Brazilian case, we can suggest legal enhancement for the long-term civil liability, the uses of the Californian carbon market, and the governmental participation reduce the chain's bottleneck.

7.5.1 Long-term civil liability

Bearing in mind that policy and framework for CO_2 storage can be a barrier to the private sector deploy CCS, comprehend how the long-term liability is addressed in Brazil is a vital issue. A previous research finding found that the activities of Capture and Geological Storage of CO_2 have been recognized as a valid and available instrument by the federal government in the last decade (Silva and Costa, 2020). Despite this, equally, it was found that the discussion on the effective interconnection between the decarbonization goals and the implementation of CCS activities as mechanisms to assist the fulfilment of the Brazilian goals is still not very present. It means that CCS activities (in its broadest sense) have not been effectively included in plans related to GHG reduction until now.

The same work shows that, until now, the specific regulatory design for CCS activities is still incipient in Brazil. There is a lack of a well and clear designed policy for CO_2 storage in terms of liability (Silva and Costa, 2020).

Despite the lack of legislation specifically aimed at the CCS operations, the existing Brazilian legislation can provide legal certainty for some activities involving carbon storage. For the analysis carried out in this article, an example of CCS-related activity whose Brazilian legislation already addresses its responsibility issue through EOR operation.

From the regulation on oil and gas exploration in Brazil and the provisions of the concession agreements in force, it is possible to identify that the Concessionaire's responsibility ends with decommissioning the concession agreements. As well know, CO_2-EOR is a method applied during oil exploitation procedures after primary and secondary phases of production (Institute, 2014), when 65% or more of the original oil in place has remained in the process. In CO_2-EOR, carbon dioxide is pumped into the oil-bearing rock formation to recover more oil. Because this method is used during the oil concession agreement, the regulation applied is the same.

According to the model of the standard Concession Agreement, drew up by the ANP, the concessionaire "will be solely responsible for his acts and those of his agents and subcontractors, as well as for the repair of any damages caused by the operations and their execution regardless of the existence of a fault, and must be reimbursed to ANP and the Union" as well as to third parties.

Regarding the Concessionaire's decommissioning or abandonment, the Concessionaire must also observe the so-called Best Practices of the oil industry, which obliges him to keep up to date with the technological, operational, and regulatory developments adopted worldwide by the oil companies in their operations and endorsed by the various class entities and the academic community.

According to the legal and contractual rules in force, the Concessionaire is responsible for repairing all damages and losses to the environment and third parties that result from operations, including those related to decommissioning.

After years of operation, when there is no longer any technical or economic viability to continue production in a given region, the production systems in a field go through a phase called decommissioning. Decommissioning is precisely the process of ending oil and gas exploration operations when an extraction field reaches the end of its economic life, involving the removal and disposal of platforms, underwater wells, pipelines, and associated infrastructure. In general, the wells are duly buffered to guarantee the isolation of clean reservoirs, pipes, and subsea equipment, thus allowing the disconnection and proper disposal of platforms and other associated assets or structures.

In Brazil, decommissioning activities are currently regulated by the ANP Administrative. Decommissioning usually comprises six main stages: (1) planning, preparation, and acceptance by the authorities, (2) removal, (3) transportation, (4) unloading, (5) separation, and (6) disposal. After all, if every step and condition are fulfilled, the concession areas can be returned to the State. As a consequence, the Concessionaire's liability ends.

Another proposal is to establish a legal enhancement to define how long the CCS operator must be responsible for the potential carbon leakage damage after the closure site.

Despite that, the acquiescence of suitable signs of legal frameworks to long-term liability, the literature indicates a possible association between the injection period and the monitoring phase in a ratio of one-third to ensure a feasible reduction of environmental risk of leakage (Havercroft, 2019). Moreover, due to the conventional method's incapability to respond to CCS needs, it may suggest the mix of conventional and innovative mechanisms to ensure the virtual zero cost for the infant industry during a reasonable period, encouraging public-private partnership (Makuch *et al.*, 2020). Therefore, the public intervention to tackle the market failure of the uncertainties input by long-term risks may boost investors to assess other predictable risks.

The standard mechanism implemented in developed countries that achieved the CCS's success is the transferring liability to the state authority under determined circumstances and duration (Havercroft, 2019).

Considering the current fragmented framework, because of the regulatory gaps and the restricted knowledge in the infrastructure law cases by any court decision, there is a need to build a body of case law and legal practices and better regulation about transfer liabilities of CO_2 from the private sector to governments. Therefore, a stricter approach could help decision-makers to build favourable institutions for the CCS business.

The suggestion is, under the Brazilian institutional framework, to transfer the liability, after a minimum of a decade and under technical approval by Regulatory Competent Authority, to the public sector designated entity to deal with the CCS issues, which may be a new public agency, a new authority, or even the current government institutions once they have proper delegation by law.

7.5.2 Determining a secular minimum time of insurance for carbon sequestration

The RenovaBio represented a pivotal opportunity to the BECCS potential in Brazil. The carbon market was concerned that it was better to have a legal system in progress than spending uncountable time trying to converge the myriad of interests.

The system above allows obtaining carbon credits through the exchange of liquid fossil fuels to ethanol or biodiesel. However, without help, the incentive has not been lucrative enough to put capture projects in operation.

Regarding the possible Brazilian biofuel’s exportation, a market that could pay competitive prices for negative emission carbon products is the Californian LCFS and its protocol, for instance, the requirement of monitoring the storage site for at least 100 years post closure.

The LCFS was first designed by the California State in 2007, via Executive Order, and via the Global Warming Solution Act, in 2006, to implement its GGR target. The system uses a market-based policy annually set by carbon intensity benchmark based on the transport sector, benefiting the use of fuels that have the CI bellow than the benchmark, and in 2018 the system includes the CCS technology as a source to generate carbon credits since it reduces transport fuels emissions of the state transport sector, mainly from direct air capture and BECCS (Townsend and Havercroft, 2019).

The Brazilian biofuels sector might benefits from implementing the CCS business into their facilities to choose the best market option considering the fuels price, the transport and exportation costs, and the profit from carbon credits in both systems (da Silva *et al.*, 2018a; Restrepo-Valencia and Walter, 2019).

To the highest LCFS credit level, the ethanol industry must ensure a long-term monitoring phase from carbon dioxide injected for at least 50 years when they need to contribute to a buffer account in the Californian market up to 16.4% of its carbon credits, or 100 years without participating to its account (Beck, 2019; Townsend and Havercroft, 2019).

An essential contribution through legal enhancement is regulating its monitoring method from the sovereign mechanism of insurance to reduce uncertainties of local Brazilian facilities and implement a negative emission ethanol fuel.

A suitable project is the Fuel Sustainability Bioenergy (FS) corn-based plant that announced the BECCS target for its ethanol, and as soon as legislation implemented a viable framework for the long-term monitoring, other biofuel plants certified by the Californian authority may seek the same fast-track carbon credit system, using the RenovaBio, the LCFS, and the potential CO_2-EOR in the offshore area or the mature fields.

7.5.3 Establishing a public apparatus to provide market failure solutions across the chain

The governmental intervention has been controversial in the last decade due to the dogmatic position from extreme divergent sides. The left-hand political parties are considered crucial to provide an effective mechanism of implementing any state decision, while the right-hand parties avoid using it once the market agents could easily capture the governmental body. Preventing this endless political controversy, the highlighting question is how the government can virtually reduce the CCS business uncertainties.

The first potential mechanism is implementing an SOE to manage the phases where market failure impedes the development of new projects. This SOE could promote cheaper transportation from a considerable number of capture agents in the industrial clusters and connect them to the storage sites. This phase has been compared to the gas infrastructure and market due to similarities between operation and facilities. However, the infant industry barriers may turn imperative to use state apparatus to unblock contractual issues of different emitting sectors trying to guarantee its interests and reduce its risks and costs. Afterward, the SOE could act as the long-term monitoring insurance, responsible for the storage assets and linked infrastructure post-closure, following the best practice that provides a minimum of risk predictability, allowing the use of LCFS to the Brazilian biofuels producers and the potential engagement of high GHG emitters industries.

The second-best possible solution is to establish public insurance funds to reduce the CCS business's private cross-chain and long-term risks. For that, it may be necessary to change existing structures to make it comfortable for decision-makers accepting a new industry as eligible to access public finance resources. The Infrastructure Guarantee Fund (IGF) aims to grant structured public guarantees against risks not covered by the market, mainly applied to conventional infrastructure facilities. The Law n. 12.712, of 2012, set up the fund, and, afterward, the Law n. 13.527, of 2017 improved the possibility to finance innovative infrastructure projects.

Considering the engagement potential of the federal government, the Brazilian IGF may assure long-term uncertainties and finance cross-chain risks to implement infrastructure from capture clusters to storage sites.

The third possible mechanism is to implement a private-only solution via the cooperative fund by all agents interested in order to dilute and attenuate individual risks via collective evolvement on the whole process.

The infant industry may not accept assume high risks and low profits under the existing scenarios. Then, the first and the second options may be more acceptable during the transition period of a convention to the low carbon economy. Finally, the private collective action could fulfil the absence of the public sector in countries which public intervention not figure as a feasible option.

7.6 CONCLUSIONS AND POLICY IMPLICATIONS

The present study was designed to explain how institutional changes could shape an intended CCS framework. The prior studies pointed out that the CCS legal gaps could lock the potential large-scale projects in Brazil. However, in reviewing the literature, the governmental incentives associated with other activities and the deployment of carbon storage projects have not been reported.

This research found that combining the current biofuel and oil areas with prospective legal enhancement could build a favourable environment for financing new business based on carbon sequestration under sectorial frameworks, mainly ancillary energy activities and its legal frameworks.

The first objective was to identify regulatory, fiscal, and financial incentives for the CCS via renewable fuels policy and mature oil fields regulatory framework.

The Brazilian carbon market may represent a key for the capture phase for CCS business since it results in CBIO improving for biofuels, being possible booster it through achieving negative emission in the biofuels plants. Besides, royalties' deduction incentives for EOR in mature fields, fiscal incentives for the oil industry, and general institutional framework may represent a path to develop the storage phase, despite the potential that could not result in carbon dioxide storage due to CO_2 supply limitations. The three findings can be accessed by the CCS players and allow economic returns via renewable energy policies and favourable institutions for the oil sector.

The second objective was to propose punctual prospective legal improvements on key gaps and other base industries.

The results indicate that solving the long-term liability coupled to the access for geological formation may unlock capturing projects from the cheapest CO_2 sources unlinked to the oil sector.

Regarding long-term liability, in summary, because there is no specific CCS regulation and restricted experience in CO_2-EOR facilities and an absence of any court decision, there is a need to build a body of case law and legal practices, as well as better regulation about transfer liabilities of CO_2 from the private sector to governments. Once ANP accepts decommissioning process for permissions (concession), it reduces potential liability against the operator in the future.

However, the potential of BECCS on the FS corn-ethanol project may need a consistent regulatory enhancement to allow permanent storage and the monitoring process for at least 50 years and, then, international carbon markets worldwide.

A path to reduce its uncertainties would be using an SOE or public-private funds to receive responsibility for monitoring carbon assets after injection, implement the transport infrastructure to link emitters clusters to storage sites without the need for business verticalization, and then reduce the cross-chain risks. In addition, the financial system may use a mix of conventional and innovative mechanisms to infant industry’s risks.

Finally, the policymakers can model competitive retrofitting auctions in the energy sector to ensure resources for paying CCS costs through tariff mechanism, possibly adding manufacturing sectors to increment the GGR in the Brazilian climate policy. These findings suggest that synergies between energy facilities in Brazil could support CCS deployment, but this may be limited by the absence of cases under judicial court to understand how it could be assessed in terms of long-term liability and the lack of CCS projects in the renewable sector.

Despite this result, it remains unclear whether the Brazilian biofuels using BECCS may compete in the international markets or remain using only the Brazilian carbon markets considering they may have different assessment of decarbonization credit and values. Furthermore, it is required to establish the viability to the transport phase regime, by regulating and incentivizing the connection from capture cluster to the injection areas (even being supported to an SOE or a public-private fund) considering the remained uncertainties and a potential solution for building up CO_2-pipelines in the institutional framework.

7.7 CHAPTER 7 REFERENCES

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8 THE INSTITUTIONAL ASSESSMENT FOR THE CCS FRAMEWORK BASED ON STAKEHOLDER'S PERCEPTION FOR IN BRAZIL

8.1 INTRODUCTION

The current state of climate change emergency has required practical actions to promote Greenhouse Gases Removal (GGR) from the atmosphere. The technological tools available make the Carbon Capture and Storage (CCS) a pivotal instrument to decarbonization, and especially considering the role of BECCS in the net-zero emission targets (IEA, 2020a, 2017; IPCC, 2014d; Kriegler *et al.*, 2017; Millar and Allen, 2020). Although it appears to have a potential 14% of the GGR contribution in the scenarios of Integrated Assessment Models (IAM), after a decade of efforts from public and private sectors, only 26 CCS large-scale projects have been in operation, which represents a small number facing the climate challenge (GCCSI, 2021; IEA, 2020a).

The CCS technology is an essential aspect for a wide range of hard-to-abate industrial sectors due to its importance of enabling a smooth low carbon transition for fossil fuels economies, allowing to take advantage of the remaining energy system and the fossil fuel facilities available on natural resources depending countries (Bui *et al.*, 2018; Clark and Herzog, 2014).

In the long term, the success of the CCS and BECCS depend on addressing the political and technical concerns in preference to orthodox financial assessment (Makuch *et al.*, 2020; Rassool *et al.*, 2020; Zapantis *et al.*, 2019).

It is inferred that the main challenge faced by researchers is the operational expenditure abatement through a diversity of methods. The cost assessment, the investment in research and development (R&D), the industrial process improvements and transparency, and the mutual exchange of expertise by countries, indicates that operational costs for capture, transport, and injection can decrease considerably once the mature phase achieves and financial support rises, which tends to turn this share of risk negligible *ceteris paribus* (Matuszewski and Detweiler, 2020; Raza *et al.*, 2019; van der Spek *et al.*, 2019).

The legal frameworks have a crucial role in defining the rule's game, the governance among the agents involved, and articulating them with other sectorial policies to build an effective low carbon business based on carbon sequestration (Havercroft, 2020; Havercroft and Macrory, 2018).

The key GHG emitters countries have to deal with correctly those rules, remaining policy changes for reducing risks, even virtually, and pricing carbon emission (Beck, 2019; Rassool *et al.*, 2020; Zapantis *et al.*, 2019). The political risks, in this work, may represent the legal and regulatory frameworks, the institutions that shape agent's behaviour under the CCS rules, and the issues related to the carbon sequestration in the international agreements that might arise in the next decades.

The institutions, in contrast, aggregates policymakers, the private sector's agents, regulators, users, and shared interests between countries and their stakeholders. Recent development in the institutional fields has led to a renewed interest in the stakeholders' perception, how policymakers understand the CCS technology in the climate change and the green new deal, the social narratives, and the interactions among sectors, and, as entities of interest groups keen on climate change policies and business, stakeholders are significant players, and they may be interested in the CCS technology's policymaking process (Terwel *et al.*, 2011).

Prior study pointed out that stakeholders' knowledge and engagement on the CCS technology may improve reliance by perceiving more negligible risks and more considerable benefits, being more likely to accept policy decisions based on trust from political authorities (Terwel *et al.*, 2011).

They already indicated the need for effective stakeholder involvement in realistic scenarios of CCS unknowledge, local participation to tackle the lack of social acceptance, and improved public engagement strategy (Brunsting *et al.*, 2011; Malone *et al.*, 2009; Mulyasari *et al.*, 2021).

In addition, the importance of corporate shareholders has been highlighted due to the disparity of companies' engagement and strategy, uncoupling its speech and core business materialized on strategic planning (Braunreiter and Bennett, 2017).

From the top-down institutional perspective, the Chinese model had tried to improve its governance on the energy sector by major reforms handled by the highest authorities of the Central Government to promote the modern mechanism of the regulated open energy market, third parties' access to essential facilities, and emission trade schemes. However, middle actors, such as SOE and local authorities, remained veto power to fragilize national clean energy-related policies (Zhang and Andrews-Speed, 2020).

Therefore, the comprehension of the middle stakeholders' perception remained unclear, how the current discourses and narratives may influence them on decision-making, the way they transform it into long-term public policies, and how it may compromise the green new deal agenda, especially into the carbon storage perspective and its application to the GGR or in the hard-to-abate sectors (Bressand and Ekins, 2021; IEA, 2019; Mabon and Littlecott, 2016).

In developing countries, the issue may become more complex due to the asymmetric information among public and private agents, the capability of coercion by organized groups to influence Legislative agenda to capture benefits through rent-seeking behaviour, and the struggle to consumers react to them.

From that perspective, in this chapter, we aim to explore the institutional framework and stakeholder's perception from the energy sector, governmental members, and researchers to better understand the decision paths to the forthcoming CCS large-scale activities in Brazil as an emerging economy.

This chapter presents the current Brazilian CCS institutional framework and the selected stakeholders' perception of CCS activities, based on organizational analysis and semi-structured qualitative data.

8.2 METHODS AND PROCEDURES

Our conceptual analysis started through how the agents influence the institutional framework in the sector they act in, what factors may shape his intentions and convictions, and how he promotes incremental changes on the current public policies and economic sectors they regulate. Then, the crucial agent of institutional changes has been how the employees are operating minor enhancements, time by time, without crossing lock-in borders, and avoiding the necessity of looking for a new social acceptance for a new technology and its associated risks than the remaining privileged position (Moon *et al.*, 2020). These individuals represent our stakeholders (social actors) as entities with their interests, converging groups, divergent agendas across sectors, or even internal complexities that make it challenging to show unambiguous decisions and strategic planning on significant enterprises and governmental entities bodies.

The study uses qualitative analysis in order to gain insights into the adaptability capacity of hard-to-abate sectors' institutions to the external factors, to the new CCS business, as well as the rigidity of implementing necessary changes to previously consolidated systems locked in patterns that make it hard to promote changes on mature sectors with habits and practices well disseminated between their agents.

One advantage of the middle-level stakeholder's analysis is that it avoids evasive statements of climate change agenda, which are suitable by decision-makers in the highest positions in the major enterprises and the government.

Thus, the research emphasizes multiple approaches, combining empirical methods by interviewing stakeholders from a group of public entities and major oil companies, and the institutional mapping process of the Federal Executive Branch regarding GGR policies in the energy industries and CCS, highlighting the middle-level positions. The data collection had occurred between 2017 and 2019 and, a qualitative analysis software was used for transcription and processing data (NVivo Software).

8.2.1 The Middle-Out Perspective (MOP) for reshaping the energy sector to the CCS activities

Before discussing the middle on energy, it is appropriate to see the top and down perspectives in the decision chain.

In the public bureaucratic and political structures, the highest decision assumes the figure of the President and its Minister (or Secretary), its public policies councils, the executive board members on regulatory agencies, and the directors of authorities, enterprises or think thanks that support the implementation of regulatory rules, incentives and penalties for unappropriated behaviour. In the major oil companies, the decisions pass through the Board of Directors pointed by shareholders and the elected Executive Board.

Considering the SOE as a part of the government, the decision-making engages the top political representation level in the Executive Branch and the oil companies' boards. Therefore, the top-down perspective is closely related to the governments and notable shareholders in the energy sector, well managed and established institutions, centralized planning process ex-ante with actions tending to lock-in (Janda and Parag, 2011; Unruh, 2000)

The bottom-up standpoint focuses on individual behaviour and grassroots economic activity, moved by opportunistic interests by stand-alone actions to capture short-term gains without thinking about its acts, collectiveness or consequences. The employees of the operational level and consumers can be classified as active agents from the bottom-up approach, taking unitary advantages of uncoordinated diffused systems and the invisible hand of the free market, in which the planning capacity of central government become limited by an institutional framework, such as feed-in tariff for solar energy (Doda and Fankhauser, 2020; Leiren and Reimer, 2018; Parag and Janda, 2010).

Primary, these methods were used to forecast hierarchical group structures on time series (Hyndman and Athanasopoulos, 2018). The MOP might combine bottom-up and top-down approaches, and it can be adapted to analyse hierarchical decision-making flowchart on governments, considering weighs from middle-level positions that may not decide the whole directive for a public policy. However, they considerably influence the political bodies to follow specific paths.

The middle-out approach in the climate change agenda may indicate how management agents from the tactic to strategic levels identify hidden barriers for institutional changes needed in the GGR policies, pointing why some actors prefer to remain locked in older agendas than in the low carbon economy.

Previous research indicates the middle actors in the energy sector being middle management on the private sector, street-level bureaucracy in the public policy level, and the communities as the agent of change (Parag and Janda, 2010).

Transposing it to the Brazilian scene on the CCS activities, the middle management (operational and tactic level) remained to be a crucial agent to de-risk institutional enhancement reducing industries resistance to new directives on policies, mainly the fear of uncertainty business of CCS against the usual developed by the Executives level on a top-down approach. The corporate perception may coincide with the incumbent position instead of the disruptive approach, highlighting the need to understand better the management and executive know-how and vision of the CCS being the oil industry's ancillary theme, strategically using its insurance of mature sector (Braunreiter and Bennett, 2017).

Instead of street-level policy agents, the bureaucracy composes the middle-level advise high-level decision-makers, such as public executives, ministers, and regulatory authorities. They can manage and deal with different interests in the Executive Branch arena, receiving divergent issues from interest groups, the unnegotiable subjects, and the public interest to promote climate agenda through sectorial policies. Therefore, they may figure as a CCS technology policy nuclei to convert the business uncertainties and previous trusts in a tangible public directive, pieces of advice, arrangements, and improving public acceptance (Brunsting *et al.*, 2011; Malone, Bradbury, and Dooley 2009; Mulyasari *et al.* 2021).

Regulators may figure in both the middle and the top approaches, depending on how developed legal and institutional frameworks are, in which mature themes tend to stay in the top level of the decision arena, differing from the current CCS status. Thus, regulators may be considered in the middle-out perspective once they act more as bureaucrats and advisors than a market regulator.

Therefore, the MOP aims to identify possible paths of internal and external influences, how they interact in sideward with other agents, how they impede the capturing temptation of policy agenda by downwards stakeholders, how they interact with upward demand from internal and external actors. Bearing in mind the concerns above, the MOP may avoid the problem of diffused interests of the myriad of consumers evolving carbon emissions, of predatory interests in the upstream chains, with well-structured groups able to use dominant position to capture public agents and consumers, and the potential to uncover hidden resistance on public agenda.

8.2.2 Analytical framework: the federal organizational bureaucracy and authorities potentially interested in CCS

In the Brazilian climate institutional framework for the energy sector and the CCS related activities, the authorities and its competencies have been exercised through a complex and uncompleted hierarchy and public policies and incentives that make CCS feasible for specific low hanging fruits; however, it did not deal properly other important GHG industrial emitters sources (Araujo and Costa, 2019). Prior comparative studies have been done analysing the CCS chain regarding its similarities with the oil sector, remaining opened the potential struggle from current bureaucracy and its institutional enhancement process (Câmara *et al.*, 2011; Rochedo *et al.*, 2016).

From this previous research, we mapped the potential agencies involved, its authorities, the stakeholders in the MOP that constitute the Brazilian energy network related to CCS, and they may influence upward decisions.

In Brazil, the allocation of authorities by the current legal framework of ancillary CCS sectors ensures national councils' participation, mainly composed of ministers, chief of agencies, specialists, and eventually, other civil society groups.

Primary directives under the jurisdictional arrangement are established by the National Energy Policy Council (NEPC, or CNPE in the native language), the Environmental National Council (CONAMA), and National Monetary Council (CMN). Just as mentioned on chapter 5, the high-level political departments' structures on the current Executive Branch that may address efforts on CCS activities are (i) Mines and Energy, (ii) Economy, (iii) Environment, (iv) Science, Technology and Innovation, and (v) Chief of Staff Cabinet.

Each ministerial bureau has authority or agency that implements public duties by supervising, licensing, regulating, establishing general norms, or promoting industrial activities through a diversity of subsidies or public funds to those who could implement the CCS in their facilities.

Ministry of Mines and Energy presents as key authorities the Minister, its deputy, and three of four finalists secretaries, which are responsible for technically advising the government on the sectorial policies. The Secretariat for Petroleum, Natural Gas, and Biofuels (SPG) is the most related area to the interrelated CCS projects, dealing with contractual clauses, bidding rounds, infrastructure, modern fuels, and the interlink between other governmental areas and energy industries.

The Secretariat for Planning and Energy Development (SPE) responds to future energy sector adaptation, ensuring energy security, adequacy, environmental concerns in the energy sector, and electricity auctions under the council directives, determining picking winners in terms of technologies or sources to energy generation.

The Secretariat for Geology, Mining, and Mineral Processing (SGM) could be related to the coal base industry, irrelevant in the current Brazilian mineral economy, the predictable energy expansion in Brazil, and geology survey implementing policies to map the CCS potential in the sedimentary basin.

Sectorial agencies might influence the long-term path of policy development via regulatory enforcement. The National Agency of Petroleum, Natural Gas and Biofuels (ANP) regulates petroleum E&P, downstream fuels, biofuels, and first-generation petrochemicals, covering fewer capture sources and storage sites coupled with oil contracts. The National Electricity Regulatory Agency (ANEEL) deals with electricity facilities and implements energy auctions that materialize governmental planning on environmental patterns and selected sources to the incremental demand of electricity on the regulated market, representing a potential incentive to implement carbon dioxide capture from thermopower plants. The National Mining Agency (ANM) may collaborate through establishing patterns in the mining industry; however, the effectiveness depends on other stakeholders' actions.

Beyond its authorities, the Brazilian Geology Survey (CPRM) may support decision-makers in the early phase of the CCS projects by providing knowledge and a technical database of potential storage sites. The Energy Research Office (EPE) may support ministers by producing studies of economics, modelling emission patterns, and sectorial enhancements connected to the CCS business.

Ministry of Economy responds to strategic federal governmental planning, finance, industrial policies, and international trade. They correspond to the follows Especial Secretaries: (i) Federal Revenue of Brazil (SRFB); (ii) Treasure and Budget (STB); (iii) Trade and International Affairs (STIA); and (iv) Productivity, Labour and, Competitiveness (SPLC), including industrial issues. At the same executive structure, ministers' decisions may solve the sectorial conflict, providing conditions for better subsidies allocation, quotas negotiations, and long-term finance policies for hard-to-abate sectors beyond energy. Despite being under Minister hierarchy, Especial Secretaries are considered high-level decision-makers positions.

The National Institute of Metrology, Standardization and Industrial Quality (INMETRO) is the federal agency that guarantees patterns and minimum standards of quality safety and environment, for instance, in the GHG emissions by-products. Despite the current absence of guidelines directly related to the CCS chain, this actor can influence its supply chain and final products when GHG emission certification becomes mandatory. The Brazilian Agency of Industrial Development (ABDI) is a para-state enterprise that aims to promote private arrangements to boost industrial sectors. Considering the CCS deployment needs as an infant industry, it plays an essential role since it enters into political agenda emerge to be prioritized. Another standardization entity to be cited is the Brazilian Association of Technical Norms (ABNT), that could help stablishing patters that allows scaled up production chain and final products.

The Brazilian Agency for Guarantee Funds and Guarantees (ABGF) has been created for assurance operations in which individual risks compromise the CCS IRR's project. The crucial role of its agency is tackling the cross-chain and the long-term risks, then, market failure is hard to solve without governmental intervention. In addition, public funds can be allocated by the Brazilian Development Bank (BNDES).

Ministry of Environment has been responsible for international agreements on climate change, negotiating changes on public policies to reshape them under environment goals, licensing process under federal jurisdiction through the Brazilian Environmental Agency (IBAMA), and regulate underground water through the competent national agency (ANA). The middle-level stakeholders are under the Secretary of Climate and International Affairs (SCIA), responsible for support ministers' decisions, and correspond to the Brazilian implementing agreements' focal point to the climate and environment issues.

The ministry of Science, Technology and Innovation (MCTI) would address long-term bottlenecks to develop basic science and potential technologies through TRL process. It may increase the potential of scaling-up of the CCS activities once the expensive carbon dioxide sources, and the potential negative emissions via BECCS are dependent on commercial scale technologies.

The coordination and mediation of divergent interests on climate change and industrial issues have been delegated to the Chief of Staff Cabinet. However, their duties might be neglected without external factors to arbitrate a decision favourable to a determined sector. Following table 8.1 summarize the mapped arrangement for public entities and the CCS chain phases they could impact.

This arrangement focuses only on geological storage of carbon dioxide. There are other analogous carbon storage techniques, such as afforestation, reforestation, biochar and soil carbon storage that present comparable pros and cons, which are not the object of this work.

Table 8.1. *Current institutional arrangement for public entities that may impact the CCS business.*

High-level Ministries	Middle-level	Competences	Rules
Mines and Energy	SPG, SPE, SGM	Monitoring, implementing, and interact with other agents regarding public policies encourage, advising ministerial councils, and support minister's decisions	Promoting CCS in the energy sector and develop the clean coal industry
	ANP, ANEEL, ANM	Inspection and regulation, implementing best practices, and support ministerial decisions	Implementing regulatory schemes for fossil fuel energy uses
	EPE CPRM	Support planning activities and long-term reports	reduce uncertainties for capture, transport (EPE), and storage (CPRM)
Environment	SCIA	The governmental focal point to climate issues, advising ministerial councils for climate, and support minister's decisions	Multilateral international agreements, federative issues, and non-financials barriers for low carbon products
	ANA	Regulation of underground water	Regulate underground water
	IBAMA	Inspection, regulatory requirements, and environmental licensing	Implementing environmental concerns
Economy	SRFB, STB, SPLC	Fiscal tax policy, subsidies, foreign trade, advising monetary council, and support economies' decisions	Tackle IRR, risks, industrial GGR, and other carbon markets
	BNDES ABGF ABDI	Development bank Agency responsible for granting special projects industrial clusters promote agency	Solving long-term liability, cross-chain risk, and short-term IRR for new projects
	Inmetro	Implementing patterns and standards for goods	The national market for low carbon goods
MCTI		Research and Development (R&D) policies	Long-term technological bottlenecks, mostly by public investment on R&D
Chief of staff		Governmental coordination of intersectoral policies	Solving internal conflicts between high-level decision-makers

Source: Elaborated by author

8.2.3 Stakeholders' perception by interview method

The research designed the interview forms regarding potential organizational and roles based on energy policies from the current institutional framework. The empirical method is based on semi-structured analytical interviews conducted with energy experts and complemented by the MOP approach (Janda and Parag, 2019; Zohar *et al.*, 2021). The semi-structured method was chosen due to the complexity of the theme and to encourage managers and policy stakeholders' interviewees to bring up their point of view comfortably on what they considered crucial to tackle climate change targets using the CCS technology.

First, it has been prepared a different set of questions to each interlocutor, considering the sector in which they worked and the commitment of its target closely related to CCS activities and their position in the decision-making chain, i.e., strategic, operational, regulatory, or advisory.

The interview's procedure aimed to prevent external bias, adopting the guidelines below. The participants were previously selected from entities in Table 8.1 to ensure comprehensive coverage of energy policy and the fundamental interest of the CCS technology. In addition, they were not informed about the "hidden theme" of the CCS Business before the interview, which was covered by the "current energy policy and its institutional framework". During the record, it prevented precipitous interventions by the interviewer to avoid undermining the interviewee and allowed thoughts freely by him to extract a comprehensive or in-depth perspective.

The interview guide consisted of three blocks, B1, B2, and B3, on table 8.3. The opening questions demanded them about prior experience, how long they have been in the current position, academic background, and, at that point, we asked them the CCS relevance in their duties. The second part mainly corresponded to questions to verify whether they are familiar with CCS technology, how the issue was managed in their areas, and how they deal with inter-sectorial needs, such as industry or environmental policies. They are also stimulated to share general perception on Brazilian NDC targets, what could be done to improve it as a path to mitigate global warming, whether they considered the CCS technology part of the climate solution and the struggling points that challenge enterprises. The concluding components stimulated experts to opine on regulatory needs to tackle the CCS barriers in Brazil, other related sectors that may be used as an anchor for developing its supply chain and business, and perspective to ramp up GHG capture and storage business.

Finally, once the main theme ran out, from general to detailed questions about the prospective CCS business, another related matter was pick up, such as bioenergy or biofuels policies. The core expectancy was keeping their beliefs, opinions, and thoughts clear, which means their cultural habits from work experience, academic understandings, and political inclinations.

Summing up, 7 (seven) recorded interviews lasted 26 minutes on average, and they were carried out with experts from middle-level Brazil's Ministry of Mines and Energy members, ANP, major oil companies, and researchers and consultants in the energy sector outlined in table 8.2.

Table 8.2. *Selected interviewees from table 8.1 to the institutional perception' assessment*

Stakeholders	Actor	Corporation	Data	Time
Operators (agents)	E1	IOC	27-Jul-18	29m51s
	E2	SOE	21-Feb-19	14m36s
Government (public policy)	G3	SPG	9-Nov-18	20m58s
	G4	SPE	9-Nov-18	20m36s
	G5	SPE	9-Nov-18	18m39s
Regulator (authority)	G6	ANP	22-Feb-19	49m09s
Researcher (agents)	R7	Modecom	22-Feb-19	33m30s

Source: author

The interviewees participated on voluntary bases, having the interview being done in person, in which they have freedom to answer under their own thoughts into the semi-qualitative guide questions, and they accepted the way the information would be treated. Due to the privacy option of the interviewees, we opt to keep them anonymous even for those unclassified to preserve the research concerns. In general, it was used the Chatham House rules.

The Transcript of each interview was recorded, and the primary qualitative analysis was done using QSR International NVivo 1.5.1 qualitative software. Afterward, critical issues have been selected manually to compile relevant stakeholder information and its positions in energy policy, which will be discussed below.

8.3 RESULTS

The Legal gaps and institutional behaviour have represented a solid barrier for the CCS business development. Brazil does not have a holistic CCS framework, although fewer incentives can be found as fragments of oil industry regulations and fiscal rules or a path linked to renewable fuel policy, as discussed in chapter 6.

On the whole, decision-makers have had a strong background in their sectors in a strict sense. They have known its duties in their middle-level positions. However, they demonstrated resistance to incorporate CCS activities into their institutional frameworks or have shown scepticism about developing it as a whole business. Following Table 8.3 outlines critical conclusions elicited from transcriptions.

Table 8.3. *Outcomes of stakeholders' interview in main subjects*

	Stakeholders subjects	E1	E2	G3	G4	G5	G6	R7
B1	Global view of climate change challenge	yes	n.e.	yes		yes	n.e.	
	Picking winners technological path issue	yes		n.e.	n.e.	n.e.	n.e.	
	The CCS business knowledge	yes		n.e.	no			
	The CCS in the policy agenda			no	no	no	no	
B2	ANP and IBAMA as Competent Authorities	yes	yes	yes	n.e.	yes	n.e.	
	MME, CNPE, and CONAMA	yes	yes	yes	yes	yes	n.e.	
	EPE and ANEEL	n.e.		n.e.	yes	yes	n.e.	
	ANM and CPRM	no	no	no	no	no	no	
B3	Constraints for transferring costs for consumers	yes		n.e.	yes	yes		
	Costs and benefits assessment needed	yes	yes	yes	yes			
	Low hanging fruits	yes	yes	yes		yes	yes	
	RenovaBio and BECCS	yes		yes		yes	yes	
	Regulatory requirements for high GHG industries	no		no	no	no		
	Fossil fuel role in the energy transition	yes	yes	yes	yes	yes	yes	
	Legal and regulatory frameworks needed	yes	yes	yes	yes	yes	yes	
	Reshaping incentives	yes						
	CO_2-EOR and CCS	yes	yes	yes				yes
	R&D policies from oil agreements and electricity			yes	yes	yes		

Notes: positive (**yes**), not entirely agree (**n.e.**), and negative (**no**). Block 1 (B1) refers to general statements and knowledge of CCS business. B2 is linked to the competent authorities regarding the CCS activities. B3 sums policies concerns and enhancement.

The enterprise's stakeholders [E1 and E2] represented major oil companies endowed with technical and financial capacities. They recognized the need to adapt themselves for the low carbon economy, and, despite that, they diverge in terms of the long-term view of its employee.

The first interview may infer that the IOC has a broad view about the climate change challenge and prospective solutions on their sectors, employees have a clear vision where the company's target and main long-term goals holistically. The second interviewee, on the other hand, the pattern of an oil company doing business as usual, focused on upstream offshore activity, and departmentalized, in which specialized sector may support finalists' activities when necessary, such as environmental concerns or regulatory relationship in the government, and then building a trust relation internally between managers.

They also show concerns about the costs for implementing any new technology or transferring it to the consumer or increasing fees and carbon tax. The increasing energy cost for consumers may cause a problem of accepting the CCS business, and it will guide the scale and the sectors firstly candidate to capture carbon dioxide [E1]. In addition, oil companies compete globally for assets, and the massive increment of taxation, even defensible, might reduce interest for new agreements [E2]. However, other mechanisms could implement fair play rules and win-win results.

Moreover, a positive point is a profitable relationship with ANP. The industry has a good thought of the ANP capacity to fulfil the competent authority gap for regulatory issues. In general, they share data and information even though it is not obligatory to prevent an accident, better understand the complexity of the hydrocarbon field in development and avoid future risks in the business. Considering the expertise built over decades, the storage phase of a possible CCS business may use the ANP institutional model as a pattern. Secondly, due to represent a mature institution, creating a new authority might not be part of the solution seeing regulatory and political risks and fiscal costs to implement it. To end, none of them consider relevant ANM as an authority to deal with CCS, at least in the storage phase. The environmental license may be under IBAMA duties, equally thought about current regulatory institutions. In sum, the critical answer is the preference to have only one competent regulatory agent instead of a board composed of any activity.

In terms of political authorities and guidelines for industries related to CCS, Ministries of Environment and Mines and Energy figure as the main actors to tackle public policies challenges. Interviewees indicate their role to provide long-term goals and strategic decisions of their path to be adopted by the country. Subnational entities might participate due to regional and local influences, mainly to avoid unnecessary resistance by local government and by public acceptance such as shale oil barriers in Brazil.

Currently, carbon dioxide storage figures only into the oil field development and management [E2], and the CCS activity cannot be assessed as a separate business. They knew injecting CO_2 increases oil recovery by the EOR methods, but they did not quantify how much oil exploited is provided by this process, which means that carbon storage is an indirect benefit of the EOR, priceless, and do not consider its environmental benefits. Due to the licensing requirements, the bottom-line standard is to inject any GHG produced, and despite the importance, only the verticalization process grows into the tools available for managers [E2].

Considering the CCS business being an infant industry, the need for regulation, incentives, subsidies, and partnership between the private and public sectors is highlighted. Even SOE has the private sector as a partner, and the decision to invest in CCS projects may have economic bases, which can be done through a diversity of instruments from new legal frameworks, current incentives, carbon credit, carbon tax, public granting, and better regulation. As an example, it is remembered that a British project has been on hold due to political changes recently, and this factor input significant uncertainties in the economic assessment.

In the oil industry, capturing costs and transporting them to offshore clusters, and injecting is a barrier to the non-vertical offshore CCS projects. The current industrial carbon dioxide is insufficient and expensive in the existing market, and only fewer onshore projects could be a target for it in the mature fields [E2].

On the other hand, energy-intensive industries can be interested in the CCS as a service and funding part of its costs [E1]. Finally, in the energy transition scenarios, available solutions will be used globally, in regional markets, and the race between technologies may result in a sum of contributions instead of predatory competition [E1].

The governmental stakeholders’ background is heterogeneous, being composed of senior supply chain managers [G3], SOE employee [G4], and ministerial public employee [G5]. Their knowledge about the CCS technology derived from other than governmental experience and other climate-related issues have been currently under political agenda. Therefore, they are more likely to respond using their own living experience. They may influence the Executive Branch statements and actions, other public stakeholders, and subnational tendencies. In addition, the long-term energy planning directives can be reshaped according to what they pointed to as relevant, such as the new energy sources that will be induced by supplying future energy demand and inducing desired behaviour from private agents voluntarily. Currently, in 2021, the know-how in the CCS business is absent almost in all agencies assessed.

Concerning the role of the CCS business for the government and its climate change goals, public stakeholders [G3-G6] revealed that the CCS activities had not been on the public agenda of the Executive Branch.

In general, they perceive new technologies' importance for tackling climate challenges long-term, and they considered relevant faced COP-21 targets. Brazil can achieve what is proposed on NDC by implementing current policies, by enhancing auctions for oil and electricity, fuels guidelines, and the principle to ensure energy security, according to the Ten-Year Energy Expansion Plan (MME and EPE, 2021). However, it is unclear when and how the CCS may contribute to Brazil achieving the GHG emission target [G4, G5]. In sum, the relevance of the CCS presented in their speeches is not linked to governmental actions and guidelines from public policies.

Prior, in terms of concept, the energy policy implementing process occurs through strategic decisions from MME to develop actions and put themes on the agenda. Hardly the regulatory agencies will change relevant paths from policies without political bases, and without political and regulatory decisions, the CCS technology does not significantly receive public funds’ allocation.

Regarding regulator speech, he directly affirms the absence of the theme in the Directive Board agenda, and, possibly, it could tangent the RenovaBio as a new carbon market to respond to Paris Agreement needs, despite the absence of carbon dioxide storage from bioenergy in an economic system.

Apropos the potential agencies for the CCS implementing process, ANP is indicated as the more favourable choice to be the competent regulatory agency due to previous expertise in the oil industry, trustworthiness, close to what will be necessary for the CCS deployment. In addition, keeping in the federal umbrella makes more sense than delegating it to subnational entities regarding environmental requirements and the conformity needed to convert it into the international commitment of GGR.

Therefore, interviewees from operators [E1, E2] and government [G3, G5] suggested submitting the environmental license to the federal agency, IBAMA, and its implicit social license process involving public hearings and judicial litigation in case of failing to accomplish its requirements and build trust between previous actors that usually diverge.

Decisions that enhance the CCS adjacent activities may receive guidelines, restrictions, and general norms and paths from ministerial councils. They pointed to CONAMA and CNPE for environmental and energy concerns, respectively, according to their usual works. The Energy Research Office (EPE), a public company dedicated to the energy studies, is recognized as an entity competent to support public policies by providing studies and reports. After being asked about electricity and its regulatory agency, it highlights its inspection function in the contracts, the restriction to act only under current rules, and the focus on tariffs to consumers. The mining agency did not appear in the interviewee's speech, even when stimulated, and they do not consider it as necessary like aforementioned to deal with a potential CCS project.

Therefore, they pointed out the need to concentrate on fewer entities to provide more effectiveness and enforcement to the authorities engaged in the CCS regulatory and institutional frameworks.

The benefit-cost ratio is a crucial vector to promote carbon storage. The cost to build the infrastructure required, return investment, and justify incremental tariffs may have a good sense of benefits to society.

The country has an NDC to be reached from the Environmental National Policy and the Paris Agreement. While they continue to accomplish without implementing onerous technologies, imposing extra costs via industrial policy may not be reasonable, which is not about merit. However, a condition due to Brazil's position in terms of renewable energy at this time and overcoming the paradigm of costs, and being economically viable by paying for environmental benefits of CCS, then the technology may receive institutional and social acceptance [G5].

The research and development (R&D) budget can be allocated to promote academic studies or conceptual and pilot projects of CCS. The idea emerged due to the existing system redirecting resources from oil agreements and electricity for developing stages and academic studies projects. The advantage is using the same framework of adjacent sectors and maintaining the CCS as a possible winner in the climate solution, such as the path chosen for the nuclear sector in the early 1970' [G3, G5].

Inquiring about improving current public policies to the low carbon economy, they first ponder their thoughts on the role of fossil fuels in the energy transition. The long-term perspective puts the fossil source as a provider of energy, transitioning to the NGPP due to the resources available in the offshore pre-salt cluster, its low emission attributes compared to other fossil fuels, and the spillover effect from the infrastructure investment required [G5, G6].

In addition, concerning the coal industry, when asked if using CCS in thermopower plants to decarbonize the coal sector, interviewee positively react much more due to its previous academic bias and experience on an SOE from a subnational federal State dependent on its sector than a guideline from energy policy or the real benefit of maintaining, in the long run, this old business [G4].

Relating to reshaping agents' behaviour, they pointed out constraints to impose additional costs for capturing GHG in the electricity, principally by crosssubsidies that have been applied widely to develop renewable energies and carry out social programs. Furthermore, setting enforcements can effectively boost CCS technology, but it is difficult to impose it for polluter's industries while the new CCS business grows [G5].

Thinking on synergies, stakeholders see mature onshore oil fields nearby industrial clusters. However, the legal enhancement is required to allow the more flexible condition to remodel incentives by royalties' reductions under the environmental policy, associated with CO_2-EOR methods or other permanent storage, avoiding rent-seeking behaviour, and following CNPE guidelines to converge governmental actions [G3].

The critical opportunity to appropriate innate skills from agriculture is to modernize the RenovaBio and adjacent policies, such as subsidies and mandatory fuels' mixture, and improve the monetization of the carbon market, the biofuels agenda, and the long-term climate agenda [G3, G6]. Bioenergy with CCS could be a possible path, including driving to negative emissions targets and compensating emissions from other sectors.

Despite that, regulatory agencies are much more dedicated to implement the carbon market and leave BECCS as a theme out of the regulatory agenda. Finally, a negative consideration is the risk of political changes through elections that contaminate the environmental policy's agenda [E1, G3].

8.4 DISCUSSIONS

The elicited interview highlighted key previous behaviours and inclinations from stakeholders to be considered in the policy agenda formation.

The success achieved for the energy sectors enforces the picking winners' problem by decision-makers, resulting in the trap of keeping transition paths joined to other public policies derived from older economic choices, such as bioenergy being the major player in the energy policy, natural gas exploitation from offshore oil fields, taking advantage of the pre-salt cluster, nuclear energy considering it economic efficacious instead of political choice result.

For institutional changes, stakeholders may prefer to submit themselves to the agencies they already have the daily practice to deal with instead of building a new office that will increase public expenses. This thought is related to the fiscal tightening and the political waves that overpass election arenas and induce institutional behaviour, interventionist or liberal, dependent on presidential polls. Furthermore, the unknown scenarios of building new relationships with other agents tend to input uncertainties for the enterprises that act in the business as usual, making the oil regulatory agency figuring as the potential authority for CCS business coherent with other countries.

In the infant industry and the propensity to avoid long-term risks, market-based agents may look for low-hanging fruits, preserving them in both situations: continuing in the climate change mitigation path, even though being fallen short then needed; and participating in the possible solutions in the unpredictable future. Prior experience may help to understand the fear of capital allocation without perception of reasonable Internal Rate of Return (IRR), configuring a market failure complex to be solved in the absence of state's intervention, creating a virtual de-risk business that transfer partially risks to the public agent (Makuch *et al.*, 2020).

The MOP process also adds the perspective of surpassing current barriers by discussing and persuading decision-makers. Middle-level agents reduce their resistance to implementing rapid changes when consented to political actors, high-level stakeholders, and benefits outweigh costs.

The feasible solutions for the CCS business in Brazil go through the RenovaBio and the oil industry's incentives, knowledge, habits, and tendencies. The current carbon market of biofuels can have value-added when coupled to carbon storage once the synergies should offset the political wear and then, reaching negative emissions in the ethanol industry as low-hanging fruit.

At the same time, the declined oil fields, their sunk cost, and available infrastructure contribute to making more competitive decarbonize cheapest captured

GHG sources in contrast to not emitters substitute goods. Moreover, the objection of direct costs allocation to the consumers is a premise in all CCS phases. The incremental costs of electricity, fuels and other industrial products can bring out organized groups and even individual citizens, building a solid net against the changes only due to the perception of poverty and inflation. Also, the method pointed out a bias to limit how much agencies may decide on CCS business to ensure empowerment of competent authorities selected, such as ANP and IBAMA being implementing regulatory and environmental roles, MME and MMA for guidelines and policies, CNPE and CONAMA for ministerial councils' decisions, and EPE supporting stakeholders as a public think tank.

Financial entities did not figure in the agents appointed for interviewees to handle bottlenecks for the CCS Business ramp-up path.

Presumably, the absence of interviewees from the Ministry of Economy resulted in a gap in their role in the cross-chain risk, the IRR, fiscal policies, subsidies for low carbon economy, or ever a broad carbon market than only biofuels with BECCS.

The long-term liability works out in the leading corner of non-technical barrier, and the participation of Economy agencies, in particular ABGF and ABDI, could get an optimistic outlook on transferring long-term liability, and accelerating CCS clusters and suppliers for its demand, respectively, and the valuable financial grants from SEF, executed by BNDES.

Another possibility has been the lack of questions directly related to financial issues for the infant industries, and then, the interviewee did not present this approach beyond the general tax reform that has been on the debate in the Legislative Branch.

Lastly, designated as critical to overpass political barriers, the high-level actors started a working group in the MME to deal with legal gaps for CCS and blue hydrogen. Therefore, a nearby future proposal from them may not surprise us to apply new rules that positively influence the CCS Business.

8.5 CONCLUSIONS AND RECOMMENDATIONS

The present study was first designed to understand how decision-makers comprehend the complexity of Brazilian NDC and the potential CCS business. As a rule, they do not consider its impact on nuclei activities where they work, and the absence of a holistic view, strategic coordination, and a mechanism to enforce CCS improvement can implicitly decode from its interviews. Mainly, the CCS technology was out of the political agenda in the Brazilian context.

Any solution for its infant industry would pass through discussions between the energy policy actors, particularly with the energy and federal environmental authorities: CNPE, CONAMA, MME, and MMA as political authorities, ANP and IBAMA for regulatory and environmental subjects, subsidized by EPE and ANEEL. The negative inclination for ANM engagement may be considered due to the cost of too many agencies deliberating on the same policy and projects.

In the enhancement of current policies, it may consider a significant constraint for increasing consumers costs in electricity tariffs, the potential of low hanging fruits in the bioenergy sector via the RenovaBio and BECCS, and the role of fossil fuels in the energy transition period due to other political and economic reasons associated with general tax reform.

The recently noticed engagement of Brazil in the net-zero emission goals changed the perspective for the CCS entering the political agenda. The attitudes shift might result from the external soft push to the climate agenda, the consequent evolution of GGR needs from companies and inland politics.

Future research might be possible to investigate middle-level actors' behaviour from complementary collecting data from the governmental agencies, such as the public financial sector, industry, and members of Congress keen on climate agenda. In addition, it could be continued interviewing specific emitters sectors and authorities linked to the current government and its political waves to try to amplify results and extract possible changes on climate change policies.

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9 CONCLUSION

This doctoral thesis research started presenting the major academic consensus based on geological climate data, which pointed that the climate change emergency has been in course since the Industrial Era, and the human activity burning fossil fuels cause environmental changes that unbalance the natural carbon cycle.

The thesis addresses the Institutional approach, the role of public sector by using arbitrating power, and the potential of the Institutional Analysis and Development (IAD) framework in the CCS activities to allow agents to deal with their carbon mitigation in the fossil fuel uses and, in the future, the potential of GGR (or CDR) goals through BECCS under appropriate conditions. The prominent outcome is that any solution for the CCS activity must consider the need for global standards in the CCS chains to scaling up the business, and the development of institutional frameworks and technologies that allows to achieve emission targets by changing production chains, consumer habits and then achieving global scale' low carbon economy and pattern.

The first hypothesis affirms that a comprehensive legal framework for CCS represents a bottleneck for deploying large-scale CCS projects, which increases risks' perception and results in long-term problems of monetizing GGR in the low carbon economy. The assumption was partially correct regarding the sole project of CCS in Brazil, and the carbon dioxide capture potential from biofuels, industries and Enhanced Oil Recovery (EOR) in mature fields.

However, normative, legal and institutional frameworks do not solve technological and cost constraints in the capture stage of prominent CO_2 industrial sources, or the transport problems to provide low cost tariffs and firm supply of carbon and then monetize the CCS business.

The Brazilian prospective CCS framework should consider a significant constraint to increase consumer costs in electricity tariffs, the potential of biofuels using the RenovaBio and BECCS, and the role of fossil fuels in the energy transition period due other political and economic reasons associated with general tax reform.

The bioenergy sector could figure as low-hanging fruit, but it needs to fulfil succeeding settings: only fermentation presents low costs at the capturing stage; therefore, the biomass-based electricity generation depends on technological deployment to reduce costs for implementing BECCS. In addition, bioenergy as a CO_2 source needs low cost of transport and scale to provide carbon dioxide and complementary solutions to deal with seasonality of sugarcane ethanol mills. Therefore, despite the potential of BECCS, enhancements are pending to solve firm demand needs to optimize capture hubs, transport infrastructure and to monetize the CCS chain.

The hard-to-abate sectors correspond to a complex production-supply chains, with business groups historically known for bargain and postpone disruptive changes. It can be in the best interest of climate policy to create institutional rules that converge major interests with the long-term migation trajectories.

The business-as-usual make it more challenging to adopt disruptive solutions for large-scale facilities. Despite that, the bottlenecks found in the institutional analysis can be adequately solved by a few procedures, such as establishing the game's rules via legal and regulatory frameworks, promoting the long-term best practices for the CCS Business through institutional and normative enhancements, incentivizing key sectors where they may appear suitable for receiving fiscal, tax, and financial policies, and when it does not result in significative costs for the society.

This work suggests an incremental approach by using legal frameworks that incorporate selected sectors, hubs or regions to develop CCS clusters in the whole chain needed, prospectively representing a commercial scale long-term target.

The Thesis' findings may help to understand the production-consumer inertia that keeps short-term cost-based methods that neglect long-term economic and environmental targets. These agents acting in the CCS chain need to properly deal with cost-effective carbon pricing, institutional perception in the different industries and the uncertainties involving decision-making and the future carbon costs.

In the political arena, the findings indicate the prominent need for national-subnational coordination, coherent legal frameworks to avoid obscuring prudent decisions under the licensing process, and incentive for starting period of the CCS industry to encourage agents to expand large-scale projects pervasively. In addition, political waves and changes, from pendular right-left wings, may break long-term feasibility once the incumbents influence the successor in the opposite direction.

This research pointed out that the most important instruments to deploy CCS large-scale projects are the emission credit schemes (such as carbon markets), governmental intervention using SOEs, tax and fiscal policies, grant supports, and regulatory requirements. The cost vector illustrates a preference for CO_2-EOR for storage and fewer low-hanging fruits in the capture for early phase.

In a contribution to the literature, the first Brazilian institutional assessment was performed. It indicated the path of creating a new public authority dedicated to regulating CCS activities, but this option implies costs and political efforts to convince the Legislative Branch of its needs.

An alternative path is to consider the governmental agencies that regulate hard-to-abate industries currently, so they might propose solutions for each sector involved in the process adapting rules to the local and the general needs. This path account with regulatory authorities of the mining, oil, water and electricity, the ministerial guidelines for political decisions into the legal framework, and subsidies provided by Brazilian Geologic Survey and the energy research agency (CPRM and EPE). In addition, the environmental licensing process may embrace federal and subnational duties.

Despite that, the complexity of a comprehensive framework may result in transactional costs that interfere significantly in the decision process.

This thesis suggests enforcing a system with a reduced number of the regulatory and political competent authorities (RCA and PCA), remaining consultive possibility for other agencies. It must be ensured they do not have divergent interests regarding CCS, otherwise it could result in a strong barrier for projects related to other sources than biofuels and NG processing plants, sectors under the oil regulatory rules and with replicable institutions in the carbon sequestration activity, and that it may result the undesirable consequences of the verticalization in the oil industry need to be better studied in the future once the ANP assume key RCA duties.

The constitutional amendment path could reduce litigation and long-term liability due to uncertainties of carbon dioxide leakage from storage sites and federative conflicts between Union, State members, and related agencies. Stakeholders might not assess this path when evaluating achievable resolutions, considering the arduous negotiation process between Legislative and Executive Branches for this kind of bill. The most plausible policy analysis pointed to an incremental system of institutional changes, sector-by-sector, to better understand agents' behaviour focus on the division of responsibilities between them and mechanisms for structural reduction of the activity's risk.

Current legal frameworks help to understand hidden rules for the incremental process on CCS business, and the institutional changes on the sectorial framework that could shape an intended behaviour to induce CCS deployment.

Merging the bioenergy and petroleum rules and improving legal nudges or minor legal enhancements may create financial opportunities for the new CCS business coupled with fuel, electricity, and oil industries and its institutional frameworks.

In the short term, the most suitable path involves the Brazilian biofuel policy, the RenovaBio, having negative emissions through BECCS, possibly supplying CO_2-EOR needs for the oil industry when feasible. Moreover, oil fiscal incentives for mature fields may anchor the monetizing process of CCS in EOR facilities. The mechanism of EOR using carbon dioxide must observe technical feasibility, for instance, adequate gravity, composition, and reservoir characteristics, and the carbon storage are much more a consequence (to be incentivized) than a target.

Regarding the regulatory bases, the countries engaged in the CCS agenda decided to adapt previous legislation, majorly introducing it into petroleum legislation and its institutional framework. Despite that, they focus more on the result than on choosing which entity might assume the competent authority for CCS technical issues.

Another challenging theme to be undertaken within the agenda has been the long-term liability regarding CO_2 storage. For that, singular schemes of public funds have assumed the ownership of the carbon dioxide after a pre-established period, under clear rules, becoming possible to exonerate operators' future leakage risks.

Finally, through the institutional perception analysis, it is observed that the enforcement of political decisions without technical support tends to create a picking winners' problem, which make the low carbon transition from older policies resulting in a hard-economic choice. The explicit example were biofuels, nuclear energy, and offshore natural gas of the pre-salt cluster.

Stakeholders prefer to deal with well-known public agents instead of a disruptive choice. They can understand what the usual actors want even when political waves change, and the possible change for a new and unpredictable RCA may create uncertainties that they are not prepared for.

In the storage phase, the competencies should be allocated under Oil regulatory Agency (ANP) due to its early expertise in oil regimes. The capturing phases may involve environmental agency as Regulatory Competent Authority, and the Ministry of Economy (ME) and Mines and Energy (MME) as Political Competent Authority, or even ministerial councils that fulfil the required high-level decisions. The crucial factor is having an arrangement that works properly, avoiding a large number of public agencies working advocating more for individual positions rather than collectively.

The incentives provided by the oil regime, the RenovaBio, the electricity tariffs, and, perhaps, the potential surplus of an international mechanism of carbon compensation or carbon markets, such as LCFS and EU-ETS, can work as carbon pricing mechanism in the early industrialization stage.

The incremental costs of electricity, fuels, and other industrial products can bring opposition from organized groups and even individual citizens, building a solid net against the changes only due to the perception of poverty and inflation. Then, to avoid it, an institutional model must be adaptable to divide the payback considering incremental gains and initial high costs.

For that, it is crucial to use financial mechanisms, public grants, and international financial support for green projects, even though they do not appear in the agent's interviewees to handle bottlenecks.

The long-term liability is a non-technical barrier, and the virtual pass through the public sector, such as ABGF and ABDI, by transferring long-term liability for other than operators, such as an SOE, and accelerating the CCS clusters and suppliers for its demand and the CCS Business ramp-up path.

The transport phase would need more attention. This sector demands optimizing of a monopolistic sector under regulatory rules pass through transparency patterns, regulated tarifs, low risks to the investors.

The institutional framework would achieve it by using regulatory best practices that, at the same time, ensure free access to the carbon dioxide sellers, in the capture side, and final disposal in the storage site. However, the market regulation could fail during the development of the infant industry, and the public sector could incentivize the connection between capture clusters and injection areas by an SOE, considering the public sector may have the power to enforce diffused losses for consumers more efficiently than a single private agent.

To put it briefly, the prospective minor enhancements could provide long-term institutional solutions to the best practices applied to the oil industry. However, the potential of BECCS in the sugarcane or corn ethanol projects may need a consistent regulatory enhancement to allow permanent storage and the monitoring process for at least 50 years and then, potentially access international markets in the future by providing a biofuel negative-emission labelled.

In addition, key market failures in the capture and the transport phases could be dealt with by using the SOE to take the risk and virtually exonerate the rest of the chain of it, to support deployment of transport infrastructure during the immaturity period, until the ratio risk-return justifies private investment.

The experience of USA and Norway on implementing CCS large-scale projects may be used as example for the Brazilian institutional framework by providing a guide on the interaction with other sectors' framework and the use of SOE as an instrument for carbon sequestration.

Moreover, it is key to standardize the whole patterns of the CCS Business, such as capture and transport infrastructure, related facilities and equipment, fluid's classification, suppliers, and other issues linked to carbon pricing. Without it, industrial scale and learning curve maturity will not be achieved.

The local facilities' costs and business' risks, institutional frameworks, and political decisions may affect the feasibility of the industrial cluster formation, in which the infrastructure is more affected by governmental decisions than private decisions of carbon markets.

The decarbonization certificate as a product of its clusters can have different price dependent on where and how they will be computed. Independently which system have been used to the GGR, the final consumer of the carbon credit could compete paying high prices for it, which induce having more influence of private than governmental decisions.

A comprehensive solution will demand complementary agreements to induce institutional frameworks, and the public-private pacts and intercountry' cooperation to tackle climate change. A single solution from governments or private sector probably will fail in achieving the CCS business scalability needed for GGR targets.

Beyond the pervasive behavioural changes needed in society for a low carbon economy, it needs a pivotal apparatus to modify the current trajectory and decarbonize industrial sectors (IEA, 2020a, 2017; IPCC, 2014d; Millar and Allen, 2020). In this scenario, CCS figures as one of the options, in combination with other disruptive technologies, and a crucial path to negative emissions at the end of the century. However, the challenge encompasses more than political desire or individual acts by enterprises, citizens, or organized groups.

Since this study is limited, we cannot state that improvements will certain result in Brazil's CCS chain's deployment. Despite that, these definitions will be needed in order to tackle net-zero targets.

Future research might investigate stakeholders' behaviour of other sectors collecting data from the governmental agencies, industries, and members of Congress keen on climate agenda. In addition, it could be continued interviewing specific emitters sectors and authorities linked to the current government and its political waves to try to amplify results and extract possible changes on climate change policies. In addition, the need for GGR will demand research in technological enhancement, mostly by public investments in the capture phase, transport arrangements, and the deployment of BECCS.

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