



TECHNOLOGICAL KNOWLEDGE PRODUCTION TOWARDS CLIMATE CHANGE MITIGATION

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Área ABEIN: 5.3 Inovação, ecoinovação, desenvolvimento e sustentabilidade

Abstract

This paper aims to present and analyze the production of green technological knowledge for the mitigation of climate change from countries and companies “carbon majors”. These countries and corporations can be identified as the largest emitters of GHG accumulated since the pre-industrial period. In turn, the “carbon majors” have historically appropriated extraordinary wealth by depleting a global resource common to all countries (global carbon budget) while generating national development. Thus, we seek to analyze a patent study to map the production of technological knowledge of selected countries and corporations that are associated with climate change mitigation and environmental management in the period 1980-2018. As a result, it has been found that technologies can be classified according to how actors position themselves in the climate change debate. Thus, the results offer evidence to both arguments that Carbon Capture and Storage (CCS) technologies may reinforce current carbon lock-in and those corporate strategies to develop such technologies focus business opportunities in a future of global mean temperatures increases exceeding 2 degrees Celsius.

Keywords: Eco-innovation, patent analysis, carbon capture and storage, carbon majors, carbon budget

JEL codes: Q54; Q55

Resumo

O objetivo deste trabalho é apresentar e analisar a produção de conhecimento tecnológico verde para a mitigação da mudança climática a partir de países e empresas “*carbono majors*”. Esses países e corporações podem ser identificados como os maiores emissores acumulados de GEE desde o período pré-industrial e que se apropriaram historicamente de extraordinária riqueza a partir da depleção de um recurso comum global a todos os países (orçamento global de carbono) ao passo que geravam desenvolvimento nacional. Busca-se analisar um estudo de patentes a fim de mapear a produção de conhecimento tecnológico, de países e corporações selecionados, associados a mitigação das mudanças climáticas e a gestão ambiental, no período 1980-2018. Como resultado, constatou-se que as tecnologias são classificadas de acordo como os atores se posicionam no debate. Os resultados oferecem evidências para os argumentos de que as tecnologias de CCS podem reforçar o aprisionamento atual no carbono e que as estratégias de corporações para desenvolvê-las focalizam oportunidades de negócios num futuro em que os incrementos médios globais de temperatura excedem 2°C.

Palavras-chave: Eco-inovação, Análise de patentes, *Carbon capture and storage*, *Carbon majors*, Orçamento de carbono.

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1. Introduction

The debate on environmental issues involving climate change began with the creation of the IPCC in 1988, which would lead to the start of climate negotiations with the settlement of a Climate Regime in the first round of negotiations in Kyoto (1997). This Regime aimed to reduce global emission levels by 5% compared to 1990 emission levels, by 2012, the initial Kyoto Protocol (KP) deadline. However, after 30 years of climate negotiations, one observes a significant rise of global greenhouse gases (GHG) emissions.

It is worth remembering that the climate regime governed by the KP was based on two guiding principles: 1) the Principle of Historical Responsibilities and 2) Principles of Common but Differentiated Responsibilities. Thus, mandatory targets were assigned to a set of countries whose historical contributions to the problem of climate change, as a function of their emissions accumulated throughout the industrial age (from 1850). The so-called “historical responsibility” of these countries reflected in the architecture of the KP, in the form of the well-known “Annex I”. The duty of industrialized countries to reduce emissions was a critical strategy that characterized the KP.

Under the terms of the Kyoto Protocol, the Conferences held for more than two decades without meeting the real commitment of the largest global emitters, as is the situation of the United States. Therefore, with the failure of the negotiated strategy – in the form of mandatory targets, associated with deadlines for compliance – global emissions have grown considerably, and national “carbon majors” states have benefited from non-compliance activities in energy, transportation, and other emissions-intensive sectors.

Well-positioned observers and renowned scholars view these negotiations on climate action as mostly ineffective. It is in this sense that Bulkeley et al. (2012) states that one must look critically at climate governance and beyond government actors. The authors recall the value of the participation of non-governmental actors in climate governance such as cities, business networks, and coalitions, countries that articulate at various levels of government, non-governmental associations, corporations and their unions and federations, professional associations, think tanks and other social actors. Accordingly, this study intends to investigate the technological strategies of both countries and companies concerning global climate governance.

This study aims to investigate the green technological knowledge production for the mitigation of GHG emissions of countries and corporations that are large global emitters of CO₂. Further, in this approach, the specific objective is to map these technologies to provide support for a discussion that includes non-governmental actors in global climate governance.

In order to achieve these objectives, a study of priority patents (as a proxy for indigenous technological production of countries or corporations) will be carried out for the period 1980-2018. Reasons for this period choice include: the development and implementations of climate change negotiations agenda, the entire duration of KP, and massive global GHG emissions growth.

In order to achieve those objectives, we seek to identify the positioning of corporate actors in the debate on global climate governance. In recent years, there has been a significant increase in patenting and in research and development (R&D) investments in carbon capture and storage technologies, mainly by oil companies’ initiatives. These technologies are capable of capturing and storing CO₂ from the atmosphere, and so they can be classified as climate change mitigation technologies.

However, one observes that these technologies are at the frontier of knowledge that is, on the one hand, associated with the mitigation of climate change by being able to capture carbon dioxide, and on the other hand, it is linked to environmental management, since they have the function of controlling air pollution. This paper seeks to present evidence to position Carbon Capture and Storage (CCS) technologies in a third way, stating that oil corporations are interested in

expanding the horizons of the oil age as much as they can and for as long as possible. This purpose would imply that CCS technologies – and the corporate strategies to develop them – may have a bias in strengthen current carbon lock-in.

This paper unveils that oil companies have increased the number of patents in CCS more than in renewable, alternative fuels associated with climate change mitigation. This finding reinforces our thesis that oil corporations' technological strategies towards climate change may strengthen carbon lock-in, as they allow corporations to keep investments as long as possible in the production of fossil fuels.

Moreover, increasing CCS development, investments and patents as a technological strategy may allow corporations to present it as their technical and even scientific contributions within global (and national) climate change negotiation fora as a means to cope with GHG mitigation to avoid dangerous climate change, and, at the same token, paradoxical as it certainly is, expanding the very time horizon of the fossil fuel era.

We recognize that carbon capture and storage technologies are expected to play a vital part in broadening the carbon budget, as it is pointed out by IPCC 2005 Special Report (IPCC, 2005). Once they capture carbon dioxide from the atmosphere, these technologies are expected to help maintain the *quantum* that can still be emitted before reaching the foreseen temperature rise. At its paroxysm, this reasoning would let companies (and nations) emitting fossil fuels forever.

This paper is organized into five sections. The next section deals with the theoretical aspects of literature. The third section presents the methodological procedures. The fourth section displays the results of the research, and the fifth section presents final considerations.

2. Background review

This section intends to recover the theoretical aspects that will support the theses presented and defended by this paper. There is an opportunity to debate responsibilities beyond government actors in global climate governance. Alongside this, we seek to characterize the countries and corporations selected for the study, besides associating to the production of technologies driven to the mitigation of climate change. Those who wish to transition to a future based on a low-carbon economy will need to increase their efforts and acquire key competencies so that green and responsible technical change is achieved.

2.1. Countries and companies carbon majors

Recently, the literature focused on the responsibilities of large corporations emitting GHG emerged. Heede (2014) has found evidence that about two-thirds of the global emissions come from large corporations producing fossil fuels and cement. According to the author, of the total emissions of CO₂ and methane between the period 1751 and 2010, about 63% were attributed to 90 entities (83 of the world's largest producers of coal, oil and natural gas and seven of the largest manufacturers of cement), then known as Carbon Majors.

The concept of carbon majors was proposed by Heede (2014) to designate large polluting corporations and holders of extraordinary market value. In this paper, carbon majors are used to denoting, in general, those who have historically appropriated the limited carbon resource, whether large corporations or countries. In this context, the debate is expanded to discuss the uneven historical appropriation of the global carbon budget.

Heede (2014) investigated in detail the anthropogenic origin of these GHGs for the largest fossil fuel producers and the global cement industry. That is, the emissions of these gases were investigated and calculated for the large private and state-owned oil, gas and coal-producing multinationals and the largest cement companies.

Heede's pioneering study led to the identification of 90 "Carbon Majors" entities as the leading industrial sources of historical emissions of these gases since 1850. This information provides means that will completely change the landscape of global climate governance as it changes the focus of responsibility for the historical emissions of countries (which were grouped in Annex I, which brought together the countries responsible for most of these historically accumulated emissions and assigned them mandatory emission reduction targets under the Kyoto Protocol).

Half of the emissions attributed to carbon majors occurred from 1986. Evidence points to an accelerated increase in fossil fuel production in the second half of the 1980s, coinciding with the proliferation of scientific studies and warnings about the causes of the transformation problem climate change.

It is also noted that there is a concentration of GHG emissions in a few countries, especially the countries of original industrialization and more recently the countries of late industrialization (such as China, India, South Africa and Brazil). Some countries account for high CO₂ emissions without a counterpart of wealth generation and development, as in the case of India, which is the eighth largest global issuer with around 31 GtCO₂ in the period 1850-2010 and GDP per capita of \$4.6 thousand. Compared to the largest global emissions, the United States, the country issued in the same period about 354 GtCO₂ and has a per capita wealth of approximately \$49.7 thousand.

Analyzed in another way, it is observed that the quantum of carbon emitted since the pre-industrial era was appropriated by a few countries. In other words, the responsibility for much of the carbon budget consumption should be attributed to a few countries and companies in the oil, gas, coal and cement sectors.

In general, this section provides evidence for the thesis that non-governmental actors should assume the corresponding share of responsibility in global climate governance. The business action for the creation of strategies, mainly technological mitigation strategies must be considered. In this sense, the next section deals with low carbon technologies and the advantages of patent studies in the measurement of technological competencies.

2.2.What are the solutions to the problem? CCS technologies as climate change mitigation.

It is widely accepted that fossil fuel-based energy consumed by the diverse economic activities is the main source of anthropogenic GHG emissions. In this sense, there are several practical (behavioral options) and technological mechanisms that can lead to possible solutions to the challenge of climate change. In consonance with Hascic and Johnstone (2009, p. 2) "the development and international diffusion of climate change mitigation technologies is key to addressing the problem of climate change". This paper intends to focus on solutions of a technological nature.

According to the Fifth Assessment Report (AR5), unavailability of CCS technologies or limited expansion of producing renewable or biomass energy can be considered an existing technological limit that has been considered insufficient for successful climate change mitigation. In fact, since the fourth assessment report (AR4) literature emerges, highlighting the importance of a systemic and intersectoral approach to mitigation, which addresses the technological, economic and institutional uncertainties needed to achieve different long-term pathways leading to a stabilization of atmospheric GHG concentrations by the end of the century. Global mitigation policies remain ineffective to promote the intended stabilization of GHGs (IPCC, 2014).

Scenarios that are more likely than not to limit the temperature increase to 2°C are becoming increasingly challenging, and most of these include a temporary overshoot of this concentration goal requiring net negative CO₂ emissions after 2050 and thus large-scale application of carbon dioxide removal (CDR) technologies (IPCC, 2014, p. 191).

These technologies are also known as carbon capture and storage and are technological applications that are not mature and have biogeochemical and technological limitations to their potential on a global scale, as well as having long term side effects and consequences (IPCC, 2014).

Hascic and Johnstone (2009) argue that within the Kyoto climate regime, the Clean Development Mechanism has sought to encourage the diffusion of technologies to accelerate efforts to mitigate climate change. Dechezlepretre et al. (2009) show that in his study that this regime induced the growth of inventive activity in mitigation technologies.

Hascic and Johnstone (2009) analysis the diffusion of climate change mitigation technologies both within Annex 1 countries and between Annex 1 countries and non-Annex 1 countries, through an empirical study based upon the estimation of two gravity models using patent data. The authors found evidence that the Clean Development Mechanism was efficient in conducting the technology transfer process between countries. However, this effect is small. These results lead us to conclude that research on associated technologies, such as carbon capture and storage, needs to be expanded.

Vormedal (2008) presents evidence on the influence of business and industrial NGOs in the United Nations Framework Convention on Climate Change (UNFCCC). Business NGOs are increasingly active under climate negotiations through lobbying. The Global Climate Coalition was a recognized lobby group about an anti-mitigation and regulation, representing the US and some European oil, coal, automobile, and chemical companies whose efforts were to obstruct climate negotiations.

The author also argues that the business and industrial lobby seeks to devise strategies to promote solutions that enable sectors such as oil, to survive, or to simply keep their businesses (carbon lock-in), or to capture new markets in an economy with increasingly restrictive carbon emissions.

These business lobbies have sought to influence international negotiations to include (geological) CCS technologies as a mitigation option in the climate regime, through the approval of CCS as a project activity under the Clean Development Mechanism (Vormedal, 2008).

2.2.1. Carbon capture and storage technologies investments from oil companies

The concept of CCS has recently been included within the UNFCCC framework, but it is increasingly recognized for its essential role in the process of mitigating climate change. The CCS presents a process of capturing and separating CO₂ from industrial sources in energy-related activities, transporting them and storing them to an isolated location for a long-term period. Stable geological formations such as hydrocarbon and aquifer fields are considered the most viable sites for such storage (Vormedal, 2008).

Data compiled by the International Energy Agency show that CCS could provide up to 55% of the emission reductions needed to stabilize global warming by 2050; if proper action is taken to increase investment and technology development, CCS can become an essential technology in the transition to a sustainable energy system over the next 50 to 100 years (Vormedal, 2008, p. 51). Indeed, CCS technologies will be needed to help reduce the CO₂ emission gap.

Climate change mitigation technologies, which have been listed in an inventory by the United Nations Framework Convention on Climate Change (UNFCCC), then called renewable energies or green energy (classified in the next section), elucidate the possibilities of nature technique to move from polluting sources based on the “hydrocarbon paradigm” to a “green paradigm” and less polluting. In other words, countries and corporations must commit to reducing GHG emissions from climate-relevant technological efforts.

One observes that among technologies for climate change mitigation, there is a growing research effort of large corporations, mainly in the oil and gas sector, on CCS strategies. An example that illustrates this point is the oil giant British Petroleum - BP, which has been involved for at least 18 years in efforts to build up technological capabilities in the field of carbon capture and storage. Unruh and Carrillo-Hermosilla (2006) claim that the company already funded an initiative of a CO₂ Capture Project that brought together energy companies for the joint development of CCS technologies. The author also claims that government actors (then the Bush administration in the United States) and non-governmental actors such as the Zero Emission Coal Alliance – which brought together nine power companies and industrial associations to commercialize CCS technologies –were interested in this endeavor (UNRUH and CARRILLO-HERMOSILLA, 2006).

Unruh and Carrillo-Hermosilla (2006) argue that the concept of carbon capture is associated with a continuity approach. That is, continuity means, by definition, to operate or make changes within the limits of the existing technical-institutional structure, which is based on the structure and development path already established. The authors show the process leads to the inertia of change. In other words, they expose a technological and institutional progress that is dependent on the precedent trajectory.

According to Vormedal (2008), CCS technologies offer an opportunity to continue using fossil fuels without significant CO₂ emissions, which makes it an attractive solution for the oil, gas, and coal sectors. In other words, by investing in these technologies, energy companies can preserve much of their existing investments in technology, know-how, and durable capital (UNRUH and CARRILLO-HERMOSILLA, 2006).

3. Data and measures

3.1. The data

In order to achieve the goals proposed in this paper, this study performs an analysis based on patent data. In general, to evaluate in which technological fields a company has sufficient competence, researchers use detailed information available in patent codes, such as those describing technology classification. Patent examiners assign at least one code to each patent according to the International Patent Classification (IPC). The IPC codes are internationally agreed, composed of 12 digits (Gonçalves, 2015). In this article, technology skills are measured based on 9-digit IPC codes, to companies and countries, grouped into five technology domains (fields), according to the clustering algorithms provided by IPC Green Inventory WIPO (World Intellectual Property Organization) and classify for us.

To search and collected the data of IPC codes was used Derwent Innovation Index and Orbit databases. Each code was classified based on its association with the development of technologies for climate change mitigation and environmental management, according to Haščič and Misoto (2015). The authors state that technologies for mitigating climate change can be classified into four types: 1) energy; 2) buildings, 3) transport, and 4) greenhouse gases. These authors, in their study for the OECD, classify CCS technologies as GHG mitigation technologies. However, WIPO classifies these technologies as pollution control. In the latter case, they would be more associated with environmental management than mitigation technologies.

In contrast to both classifications, this study considers a third research front that is aligned with corporate strategies, especially from the 1980s. It is believed that corporations and hence countries are not interested in the air pollution control or projects of GHG mitigation, but are interested in maintaining, as much as possible, the investments made in the fossil-intensive paradigm. This can also be called carbon lock-in. Therefore, technologies are classified according to how the actors position themselves in the debate. Table 1 displays the technological domains.

The priority patent data³ was used as a proxy to measure country technological knowledge production in their respective technological fields and then grouped according to the five environmental technology classifications. The priority patent is a proxy that has the purpose of measuring the national production in the said technological field. The data were collected from Orbit database for the countries. For the companies, we used to Derwent Innovation Index⁴, both in the period from 1980 to 2018.

Table 1. Environment technologies to climate change mitigation, and green technological classes

Environmental Classification	Technological Domain	Technological Fields (WIPO)
Environmental Management	Air pollution abatement	Air quality management
	Water pollution abatement	Control of water pollution
	Waste management	Waste disposal
		Treatment of waste
		Consuming waste by combustion
		Reuse waste of materials
	Environmental monitoring	Means of preventing radioactive contamination
	Soil remediation	Forestry techniques
		Alternative irrigation techniques
		Pesticides alternative
		Soil improvement
Climate change mitigation (Energy generation, transmission or distribution)	Renewable energy generation	Wind energy
		Solar energy
		Geothermal energy
		Hydro energy
	Energy generation from fuel non-fossil origin	Biofuel
	Nuclear energy	Nuclear energy
	Enabling technologies in the energy sector	Fuel cells
		Power supply circuitry
		Storage of electrical energy
		Recovering mechanical energy
	Others	Devices for producing mechanical power from muscle energy
		Harnessing energy from manmade waste
		Waste heat
		Natural heat
Climate change mitigation (buildings)	Energy efficiency	Low energy lighting
	Thermal performance of buildings	Thermal building insulation, in general
Climate change mitigation (transportation)	Transportation	Vehicles in general
		Vehicles other than rail vehicles
		Human-power vehicle
		Rail vehicle (drag reduction)
		Marine vessel propulsion
Capture, storage and sequestration or disposal GHG	CO ₂ capture or storage (CCS)	Carbon capture and storage

Source: by authors based in Haščič and Migoto (2015) and IPC Green Inventory.

³ The patent application priority refers to the claimed priority, i.e. is the same as the application of the priority document claimed. The priority number is composed of a country code (two letters). From this code, the data were collected. Each country has its registration number. However, ESPACENET (European Patent Office) states that in general, in addition to the country code, the number is composed of the year of the deposit (four digits) and a serial number (variable, seven digits).

⁴ Derwent was used to collect data from companies, since this base allows the collection by company code. Orbit does not allow this type of search. The search for companies by word is flawed since it can identify the homonymous names of non-companies.

3.2. Measures: patents statistics for analyzing the green technology nature

This section aims to describe the methodological procedures used to evaluate the stock of green patents for countries and companies.

This paper uses the following three indicators:

1) Revealed Technological Advantage Index (RTA) (Patel and Pavitt, 1997; 2001, Nesta and Patel (2005) is an indicator similar to the traditional comparative advantage indicator proposed by Balassa (1961) to evaluate the specialization in international trade. The result of RTA varies between the interval $[0; +\infty]$. For values above the unit, it is interpreted that the company or country has a technological advantage in the technological field. Given the great interlocation and the absence of an upper limit, the results may be biased. In order to eliminate the bias, one uses a standardization in which may "force the RTA index to take values between -1 and +1 by computing the ratio of RTA minus one over RTA plus one: $NRTA = (RTA - 1)/(RTA + 1)$ "⁵ (Nesta and Patel, 2005, pp. 538). The RTA is defined as:

$$RTA_j = \frac{\frac{P_{ij}}{\sum_j P_{ij}}}{\frac{\sum_i P_{ij}}{\sum_{ij} P_{ij}}} \quad (1)$$

2) patent share (PS) of green patents in the technological domain i by the country or company j

$$PS_j = \frac{P_{ij}}{\sum_j P_{ij}} \quad (2)$$

3) coefficient of variation (CV) of the RTA. According to Nesta and Patel (2005), CV serves to determine if a country has established niches of technological excellence or extended its national technological competencies to a broader spectrum. Thus, one can calculate the coefficient of variation for a given indicator as to the RTA, for example.

$$CV_j = \frac{\sigma_{RTA_{ij}}}{\mu_{RTA_{ij}}} \quad (3)$$

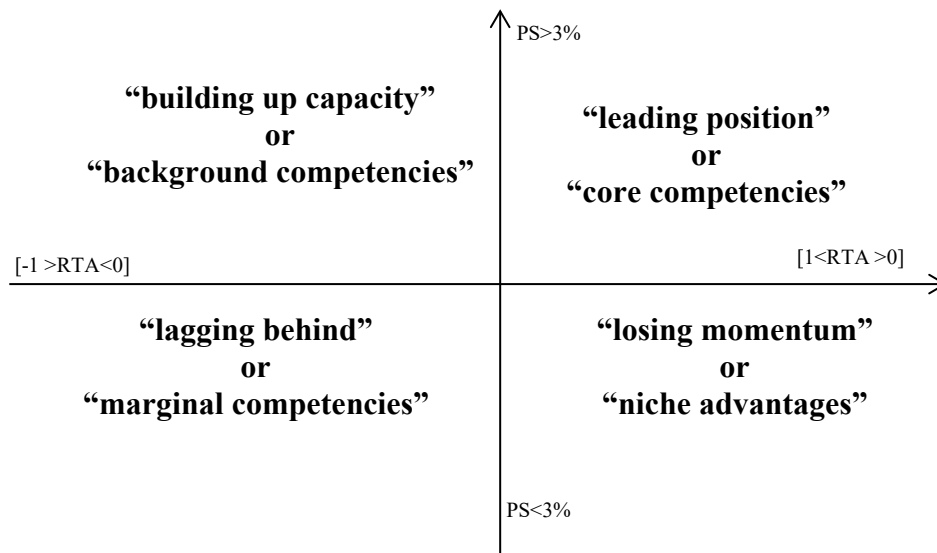
where, for a given country j , the CV_j is the coefficient of variation of the RTA, σ represents the standard deviation and μ are the arithmetic mean of the RTA values. The result reveals a measure of the concentration of patent counts among the green technological domains: a high CV means that the country or company is concentrating its areas of excellence within a range of technological competencies. On the other hand, a low CV means that the country is developing its skills uniformly across the full range of technologies. Thus, the indicator is capable of providing information on the degree of technological specialization within a country/company. Similarly, Eq. (3) can be easily extended to CV_t which measures the concentration of patent counts between countries or firms for each selected green technological domain. This tells us whether a given class of technology is concentrated in one or a few countries/companies, or it is more dispersed (Nesta and Patel, 2005).

⁵i.e. $NRTA \in [-1 ; +1]$.

From the first and second indicators, it will be possible to build charts that will allow the mapping of green technologies and then visualize the green technological profile from the technological competencies classified in quadrants framework.

We follow the classification of Nesta and Patel (2005) to show the technological competencies in the green domains of the countries that are acquiring for the mitigation of climate change, they are: “leading position”, “building up capacity”, “lagging behind” and “losing momentum”. The initiatives of companies in the construction of green technological competences are classified according to the study of Patel and Pavitt (1997), whose classification is: “core”, “background”, “marginal competencies” and “niche advantages”. By merging the two methodologies of the authors, the map of green technologies will be as figure 1 below.

Figure 1 - Technology map of countries and companies



Source: prepared by the authors and inspired by Patel and Pavitt (1997) and Nesta and Patel (2005).

4. Mapping Green technological knowledge production to climate change mitigation and environmental management

This section aims to map the green technological production to climate change mitigation, mainly in the energy, transport, buildings technologies and technologies associated to environmental management, by 25 countries and 20 selected companies from 1980 to 2018.

Table 2 provides the patterns of green technological advantage by RTA index and measures the specialization through the coefficient of variation. So, the last column of the table shows the coefficient of variation of RTA values per countries (CVi) that reveals the specialization in the technologies categories and CVt per technologies, in the last line, reveals the degree of technological commonality across countries and some interesting patterns (NESTA and PATEL, 2005).

The selected countries with the highest degrees of technological diversification measured by CVi in the fields of mitigation and environmental management were Germany (11.21), the Netherlands (24.45), Spain (25.10) and Japan (25.49). The mean of the results for CVi was 45.37, for the 25 countries. It is worth mentioning that the developing countries that make up the BRICs (Brazil, Russia, India, and China, except South Africa) were below average. That is, they had a low degree of specialization or a high degree of diversification in the selected technologies.

About the results of the technological concentration, CCS technologies were the ones that obtained the highest result (71.51). It is worth remembering that this class was measured from only one technological field. In this technological field, the country that presented the greatest technological advantage was Canada (3.57), followed by the United Kingdom (2.61), USA (2.59) and Kazakhstan (2.44). It is no wonder that these four countries hold the largest reserves of oil in the world, according to data from the CIA World Factbook⁶.

In turn, the largest global GHG emission country, the US, presented the highest RTA in the carbon capture and storage technology field, followed by the alternative energy production field to mitigate climate change. In the field of environmental management, the country had an index below the unit, which means that it has no technological advantage when compared to other countries. Only four countries did not present advantages in this field, besides the USA, they were: the United Kingdom, Germany, France, and Japan.

Table 2. Patterns of Green Technological Advantage, RTA in selected carbon majors' countries, 1980-2018

Country	Energy	Transport	Buildings	CCS	Environment	CVI x100
USA	1.14	1.01	1.06	2.59	0.69	50.98
China	0.96	1.03	0.57	0.66	1.20	26.47
Russian Federation	1.01	0.42	0.44	1.26	1.36	44.38
Germany	0.98	1.26	1.07	1.13	0.92	11.21
United Kingdom	1.01	0.97	1.01	2.61	0.91	50.25
Japan	1.05	0.95	1.51	0.79	0.79	25.89
France	0.99	1.25	0.98	2.24	0.88	39.52
India	1.00	1.19	0.22	1.10	1.18	39.03
Canada	0.86	0.88	0.97	3.57	1.13	70.56
Ukraine	1.01	0.28	0.44	0.90	1.43	50.81
Poland	0.99	0.31	0.69	1.17	1.35	40.44
Italy	0.75	1.97	0.68	1.07	1.13	41.00
South Africa	0.74	0.52	0.29	1.12	1.78	58.66
Mexico	0.73	0.37	0.98	0.99	1.63	44.02
Australia	0.84	0.75	0.93	2.33	1.28	47.28
Korea (South)	0.89	0.95	1.47	0.58	1.06	29.22
Spain	0.80	0.92	1.07	0.62	1.32	25.10
Kazakhstan	0.78	0.33	0.62	2.44	1.61	66.27
Belgium	0.82	0.59	1.58	0.58	1.25	40.77
Iran	1.23	0.35	0.00	0.00	1.24	99.67
Czech Republic	0.90	0.48	0.82	0.72	1.40	35.18
Brazil	0.78	0.98	0.50	1.06	1.49	33.73
Netherlands	0.81	0.94	1.01	1.58	1.28	24.45
Indonesia	0.67	1.05	0.59	0.00	1.66	69.27
Saudi Arabia	1.12	0.44	0.49	0.00	1.23	70.01
<i>Number of RTAs above unity</i>	8	7	8	14	20	
<i>Concentration (CVI x100)</i>	15.34	48.66	48.86	71.51	21.60	

Source: prepared by the authors, from research data.

Figure 2 (2a through 2d) shows the technologies for climate change mitigation and environmental management produced by the major GHG-emitting countries. The mapping of these technologies was done through the revealed technological advantage index and normalized by symmetry, in order to find in the axes x's the technologies with higher and less advantageous. In the

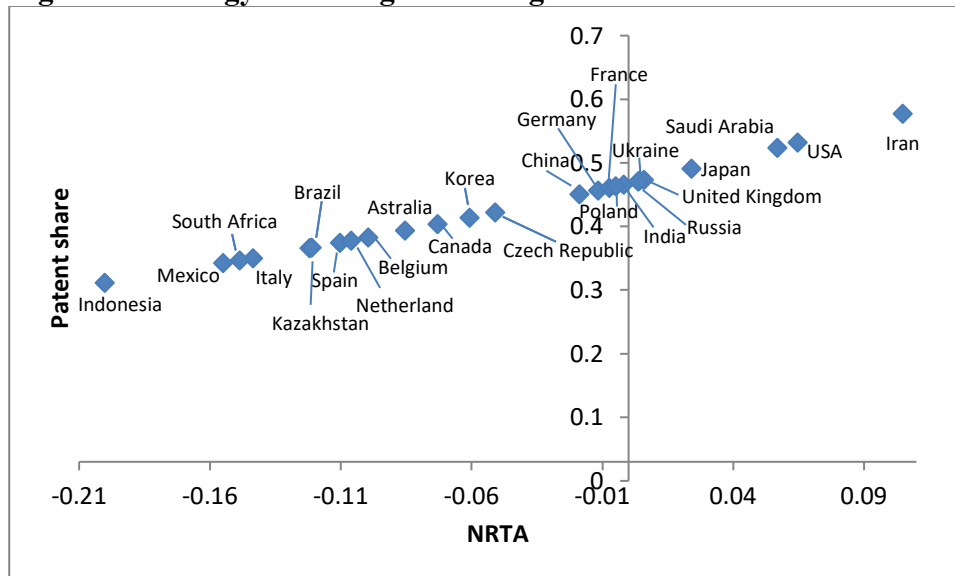
⁶I.e. the ranking of the selected countries with the largest oil reserves in the world: 1st Venezuela, 2nd Saudi Arabia, 3rd Canada, 4th Iran, 5th Iraq, 6th Kuwait, 7th United Arab Emirates, 8th Russia, 9th Libya, 10th Nigeria, 11th USA, 12th Kazakhstan, 13th China, 14th Brazil, 25th India, 30th Indonesia, 32nd United Kingdom and 38th Australia. The source is available in <https://www.cia.gov/library/publications/the-world-factbook/rankorder/2244rank.html>.

y-axis show the share of the technologies in the total portfolio of each country. The indexes greater than 3% is above the x's axis, similar to that made by Patel and Pavitt (1997).

Therefore, Figure 2a reveals technologies associated with mitigation of the energy sector, being an important and strategic sector for climate change. This technological domain is composed of technologies associated with the generation of renewable energies (solar and wind, for example), production of biofuel, among others. Thus, in the upper right quadrant are the countries Ireland, USA, Saudi Arabia, Japan, United Kingdom, Russia, and Ukraine. Therefore, the results show the leadership of these countries in the production of technologies associated with the mitigation of climate change related to the energy sector. The other countries, comparatively, do not present technological advantages in this field, were then classified as building up capacity technological competencies.

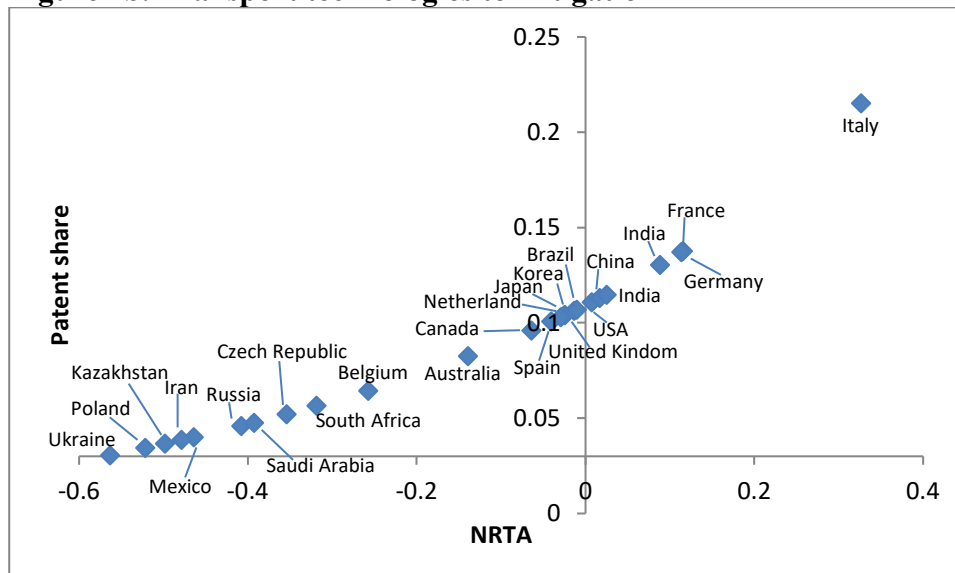
Figure 2. Mapping the technologies to climate mitigation and environment management, 25 top countries carbon majors (1980-2018)

Figure 2a. Energy technologies to mitigation

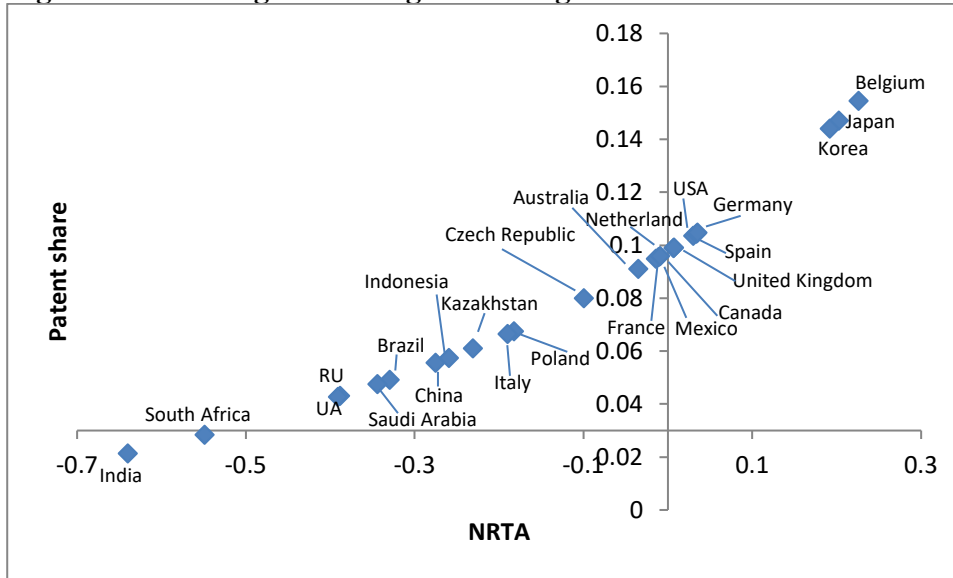


Source: prepared by authors

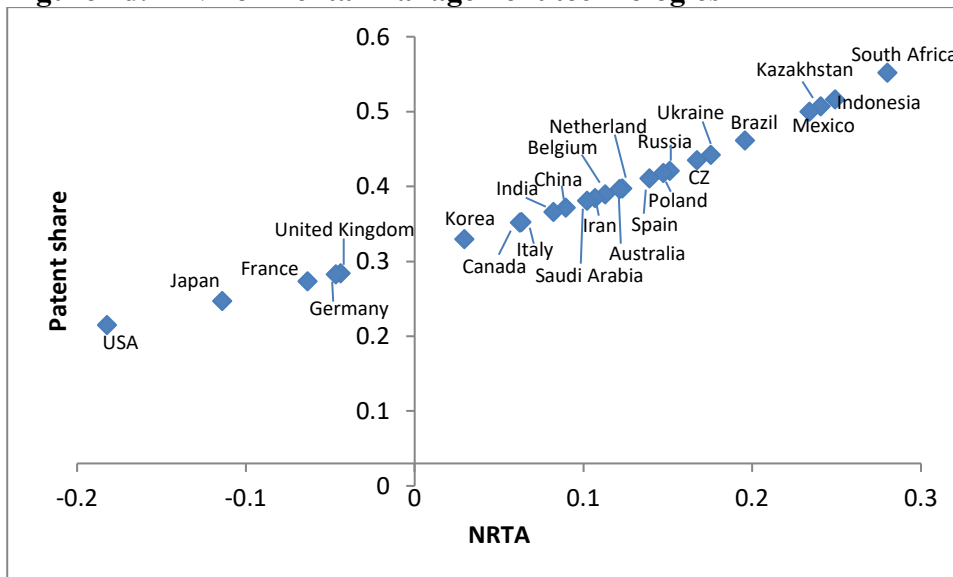
Figure 2b. Transport technologies to mitigation



Source: prepared by authors

Figure 2c. Buildings technologies to mitigation

Source: prepared by authors

Figure 2d. Environmental management technologies

Source: prepared by authors

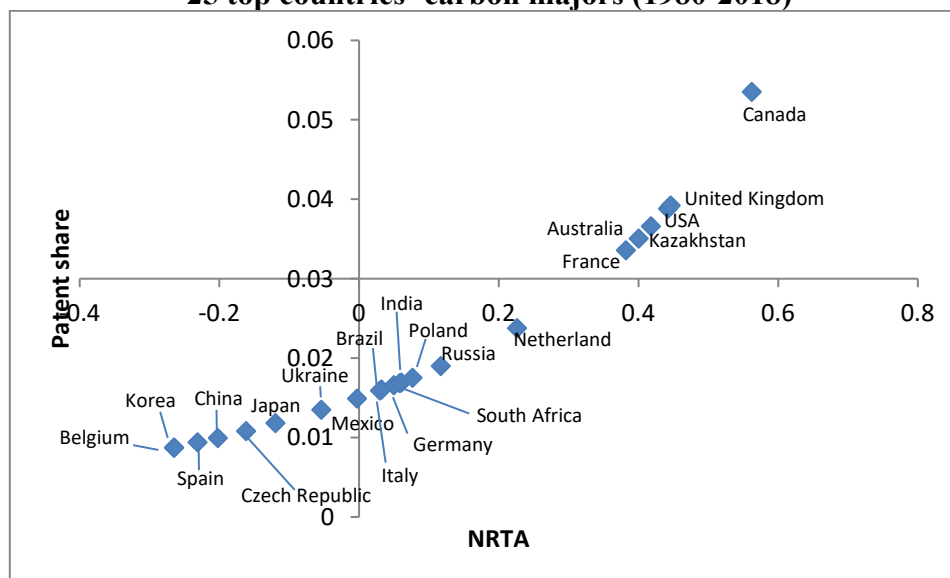
Italy stands out with the greatest technological advantage in the field of transport. In the construction sector, the countries with the greatest technological advantage are Belgium, Japan, and Korea. Finally, in environmental management, almost all countries had an advantage in this technological field, with a greater emphasis on South Africa, Indonesia, Kazakhstan, Mexico, and Brazil.

Figure 3 shows the cross-reference between the results of the normalized revealed technological advantage and the share of priority patents for 25 carbon majors' countries for CCS technologies. CCS technologies play an important role in serving to reduce the CO₂ emission gap. In this sense, the figure aims is to map and identify the countries that have the greatest advantage in the production of knowledge in this technological field to reveal those who are ahead in this process. Countries such as Canada, United Kingdom, USA, Kazakhstan, Austria, and France are located in the upper right quadrant, which shows the leadership of these countries over other carbon majors. According to Nesta and Patel (2005) they can be identified as leading position technologies,

within a portfolio of green technologies, in other words, identifies the pattern of green technological accumulation of the countries to the mitigation of climate change, besides indicating a concern with the control of the pollution air.

It is also noted that the results for the Netherlands, Russia, Poland, South Africa, India, Brazil, Germany, and Italy were classified as “losing momentum”. This means that they have technological advantages over the other countries carbon majors, but the degree of patenting in relation to the total did not prove significant. The Brazilian highlight in CCS technologies is since Petrobras has been involved in carbon capture projects since the 2000s.

Figure 3. Mapping the carbon capture technologies, 25 top countries' carbon majors (1980-2018)



Source: prepared by authors

Table 2 shows the results of the RTA for 20 top carbon majors companies, with their respective coefficients of variation. The technological domain with the highest number of companies with RTA above the unit is the energy sector. As already mentioned, this sector is relevant to the process of climate change mitigation. As all the selected companies are oil sector, therefore they carry out activities in the energy sector. Another technological field with the most prominence is that of CCS technologies, which had ten companies presented technological advantages in these technologies, especially the Spanish company Repsol and the Norwegian company Statoil with the higher RTAs in this field. It is noteworthy that all the companies had priority patents granted in this field.

The CVi revealed a high specialization of the Australian company BHP with a CVi of 179.34, given the high degree of the RTV in the field of construction. The most technologically diversifies companies were ExxonMobil, BP, and Chevron.

In a neo-Schumpeterian reading, the identification of the determinants of technological change is essential if one wishes to transition to a low-carbon future. Under this approach, it is observed that the companies represent the locus of innovation which accumulating knowledge and learning, as well as being technological capabilities that make possible the change of the system.

The premise is that technological change represents the motor of capitalist development, as interpreted by Schumpeter; from it, analytical strategies of a qualitative nature, with an essentially historical basis, are mobilized alongside quantitative data, to analyze how innovations are generated and diffused in capitalism (FREEMAN, 1987).

**Table 2. Profile of Green Technological Advantage,
RTA in selected carbon majors companies**

Country	Energy	Transport	Buildings	CCS	Environment	CVi x100
Chevron	1.23	1.89	0.93	1.39	0.62	35.21
ExxonMobil	1.24	0.81	0.71	1.43	0.64	32.15
Saudi Aramco	1.21	1.95	0.23	1.94	0.43	62.91
BP	1.28	0.45	1.01	1.24	0.69	34.22
Gazprom	0.95	0.32	0.55	1.57	0.84	50.20
Shell	1.31	1.62	0.97	1.33	0.59	30.38
Pemex	1.01	0.00	-	0.52	1.25	91.84
ConocoPhillips	0.99	2.67	0.69	1.64	0.70	56.22
Total	1.71	1.00	6.15	0.77	0.41	105.34
PetroChina	0.82	1.14	0.44	0.80	1.24	31.69
BHP Billiton	1.30	0.77	29.55	0.07	0.54	179.34
Petrobras	0.61	0.58	-	1.30	1.23	64.45
ENI	1.01	-	1.75	0.45	1.23	68.54
Occidental	1.16	-	-	0.67	1.06	86.47
Statoil	1.18	-	0.47	2.16	0.41	78.30
Lukoil	0.70	2.92	-	0.76	1.29	86.67
Sasol	1.21	1.79	-	0.54	1.01	66.55
Repsol	0.70	6.43	-	2.78	0.34	116.75
Marathon	0.81	1.43	-	1.24	1.06	54.81
Sinopec	0.72	0.59	0.39	0.61	1.42	47.41
<i>Number of RTAs above unity</i>	12	9	4	10	9	
<i>Concentration (CVj x100)</i>	25.47	108.01	292.57	55.53	40.38	

Source: prepared by authors

Figure 4 shows the green technological profile for 20 companies in the oil sector. The objective is to map the production of technological knowledge to the climate mitigation produced by the largest global polluters, according to Heede (2014).

The energy and transport sector can be considered emission-intensive, as energy production and transport use are increasingly dependent on fossil fuels. In this sense, these are sectors that deserve to be carefully analyzed. In mitigation technologies in the energy sector, the French company Total (PETF – Derwent code) has stood out with a great technological advantage. This company has shown technological advantages in the renewable energy sector, specifically in photovoltaic technology production.

Still in the technologies of the energy sector, other companies that stood out with core competencies are: European Shell (SHEL) and BP (BRPE), Australian BHP Billiton (BRHI), South African Sasol (SASO), US companies ExxonMobil (ESSO), Chevron (CALI) and Occidental (OCCI), as well as Saudi Aramco (SAOI), Statoil (DENO), Mexican Pemex (PEMEX) and Italian Eni (ENIE). The company that presented the lowest technological advantage in the energy sector, among the selected companies, but classified as background competencies were the Brazilian Petrobras.

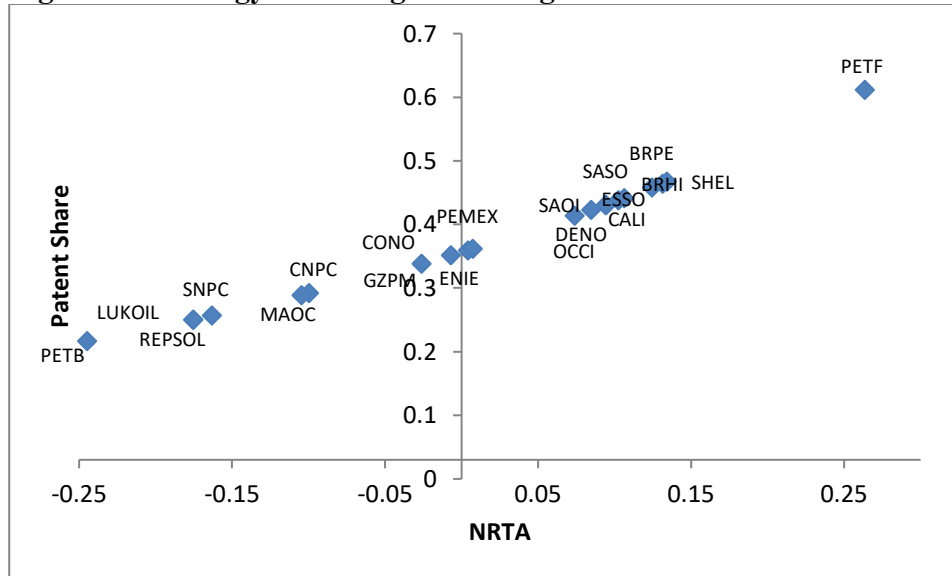
As already mentioned, the transport sector has its emissions associated with the use of means of transport carbon-intensive, such as passenger cars, public transport buses, trucks for the agricultural or manufacturing production flow, for example. Thus, technological initiatives that minimize emissions associated with these economic activities are increasingly required. The oil

company that has been most engaged in technology' production to mitigate the transport sector was Repsol (REPSOL).

Only two companies presented core competencies for the mitigation in the building sector, the companies BHP Billiton (BRHI) and Total (PETF). In technological production for environmental management, the Chinese company Sinopec (SNPC) had the biggest technological advantage among the selected companies' carbon majors.

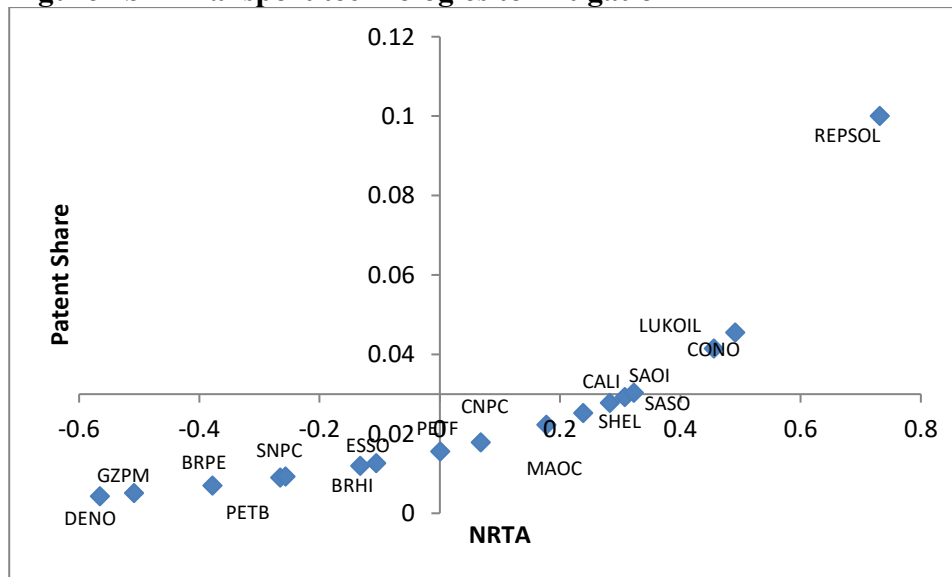
Figure 4 –Mapping the technologies to climate mitigation and environment management, 20 top companies' carbon majors, (1980-2018)

Figure 4a - Energy technologies to mitigation

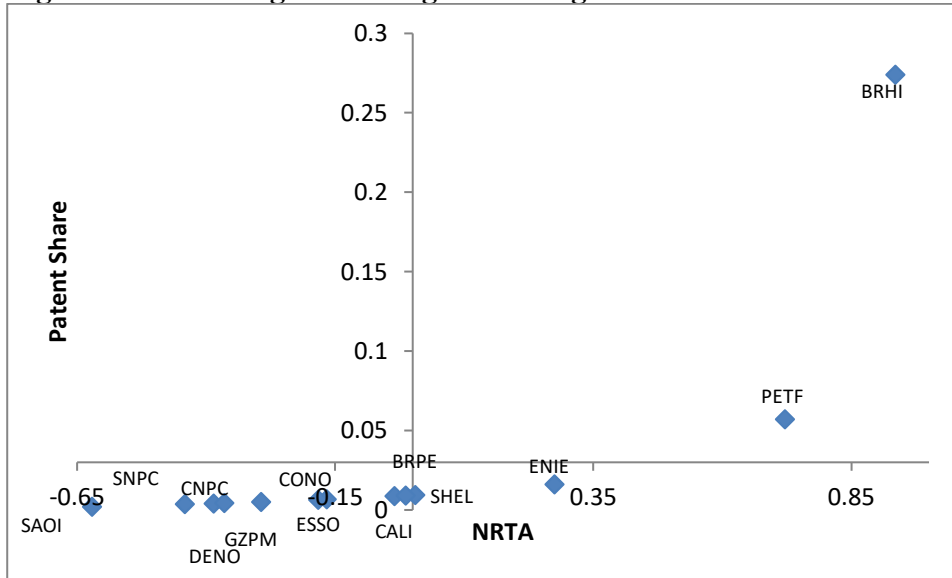


Source: prepared by authors

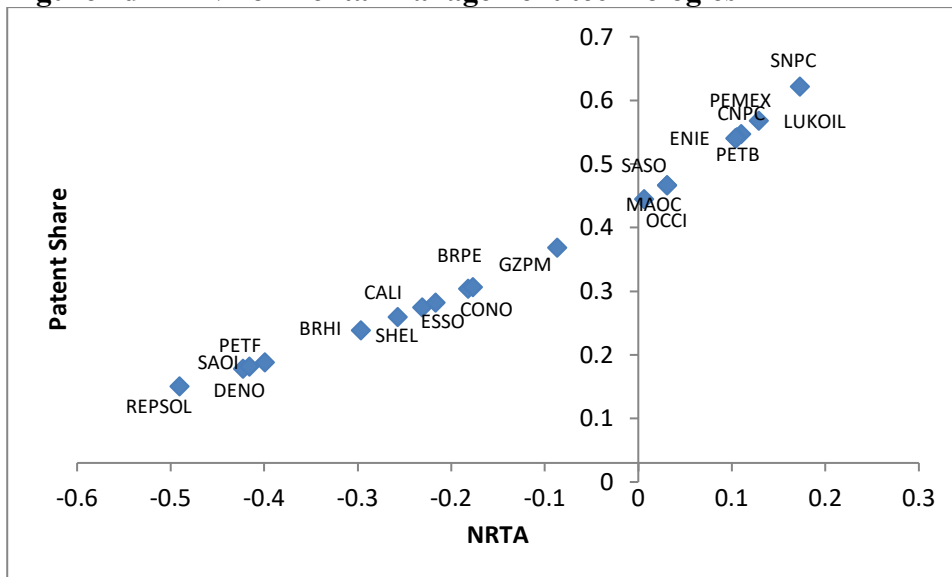
Figure 4b – Transport technologies to mitigation



Source: prepared by authors

Figure 4c – Buildings technologies to mitigation

Source: prepared by authors

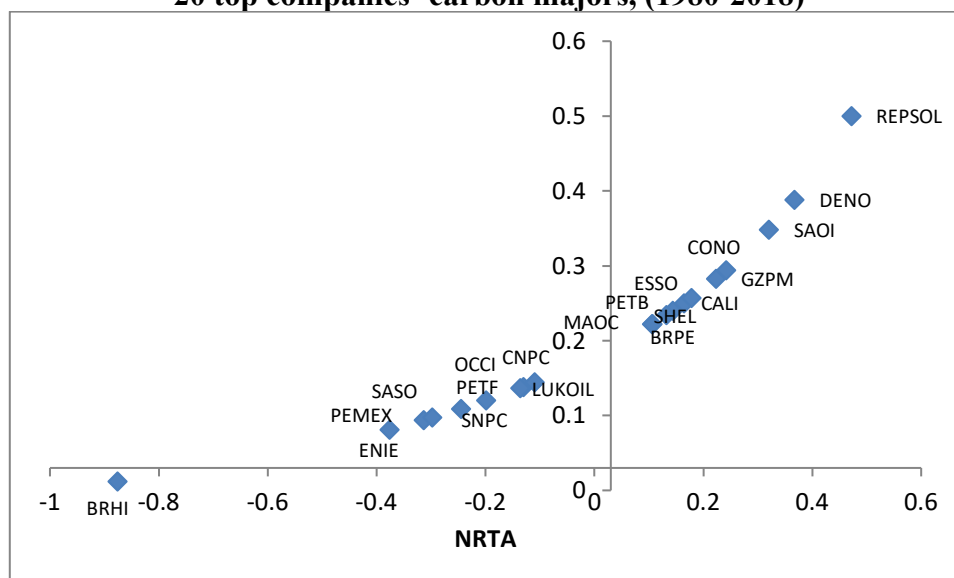
Figure 4d – Environmental management technologies

Source: prepared by authors

Note: The companies are ranked by the biggest polluter and with their respective search codes in Derwent: Chevron (CALI), ExxonMobil (ESSO), Saudi Aramco (SAOI), BP (BRPE), Gazprom (GZPM), Shell (SHEL), Pemex (PEMEX), ConocoPhillips (CONO), Total (PETF), PetroChina (CNPC), BHP Billiton (BRHI), Petrobras (PETB), Eni (ENIE), Occidental (OCCI), Statoil (DENO), Lukoil (LUKOIL), Sasol (SASO), Repsol (REPSOL), Marathon (MAOC), Sinopec (SNPC)

Figure 5 presents the technological profile for 20 oil majors in the CCS technological field. In the upper right quadrant are found eleven companies that are classified as core competencies. It is noted that oil companies are acquiring technological competencies that will capture or sequester carbon dioxide in the atmosphere. The technological advantage, during the period, in this field is greater for Repsol, Statoil, Saudi Aramco, Conoco, Gazprom, Chevron, ExxonMobil, Shell, Marathon, Petrobras, and BP.

**Figure 5 - Mapping the carbon capture technologies,
20 top companies' carbon majors, (1980-2018)**



Source: prepared by authors

5. Conclusions

The paper aimed to investigate and map the strategies of countries and corporations of the petroleum sector, classified as carbon majors, to evaluate and quantify the production of green technologies to mitigate climate change. This study aims to contribute to the debate by presenting the strategies of companies that are said to be committed to a future low carbon economy within global climate governance.

It is observed that in aligning the technological strategies of the companies, CCS technologies have a special place. These technologies could be used in the future as advanced oil recovery. In this way, this technology has noteworthy interests and investments within oil companies.

In this sense, the paper has shown that the interest of oil and gas companies that can be associated in reinforcing the technological carbon lock-in, because of the interests of incumbent companies in the long-term stay in the energy system associated with the carbon-intensive paradigm. These companies made high sunk investment and, therefore, they are demanding the maximization of the returns of the assets invested. Besides, these companies have built and accumulated skills, knowledge, and technical learning that hinder the transition to other market sectors. The company always will invest in what it knows how to do (its core business). These propositions are corroborated by the patentability of these companies in the CCS technologies and the energy sector for GHG mitigation. It is worth remembering that investments in research and development are a means by which the company seeks to do something new, besides expanding the absorption capacity.

Additionally, the IPCC has stated that without carbon capture technologies, it will not be possible to overcome the emissions gap. These technologies should be necessary to ensure the reduction of the CO₂ emissions gap. The UNFCCC scenarios point out that these technologies must be combined with other technologies responsible for reducing GHG emissions, as such renewable energies.

It has also been pointed out, in this work, that the production of technologies in the energy sector to mitigate climate change has also attracted the attention of selected companies in the sector, especially the French company Total, which has patents granted in the area of renewable energy.

The transportation sector is intensive in the use of fossil fuels and is also a target sector for oil companies but in a reduced effort of technological investments and patent production. However, some companies have engaged in the production of technological know-how in the transportation sector ensuring core technical skills, such as the Spanish company Repsol.

As has been shown, companies are building capacity in activities associated with their own sectors of activity (such as climate change mitigation technologies in the energy sector). In addition, there was a greater investment and technological effort in CCS. Companies that are engaged in this venture expect that this stored carbon will, soon, be used as advanced oil recovery.

Moreover, the fact that the oil lobby finances corporate NGOs to influence negotiations under the UNFCCC leads us to conclude the severe interest in CCS technologies will continue to call for further research efforts. A research agenda, from both a Political Economy and an Industrial and Innovation Policies accounts, would have to include themes as further mapping of corporations' R&D investments and patents on CCS technologies, regulation and other public policies in the interest of constructing a future where fossil fuels are still needed, but have to be strictly managed in order to restrict CO₂ emissions effectively.

Finally, one notes the urgent need for a large-scale technology change in various sectors to mitigate climate change, beyond energy. That would require more diversified competencies and could not be concentrated in the sectors that the companies already have technical knowledge. In low carbon future, CCS may have its place, but technological strategies must go much further.

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