Instituto Alberto Luiz Coimbra de
Pós-Graduação e Pesquisa de Engenharia
COPPE UFRJ

PROPOSAL FOR THE IMPLEMENTATION OF A CARBON PRICING INSTRUMENT IN THE BRAZILIAN INDUSTRY: ASSESSING COMPETITIVENESS RISKS AND DISTRIBUTIVE IMPACTS

Luan dos Santos

Tese de Doutorado apresentada ao Programa de Pós-graduação em Planejamento Energético, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Planejamento Energético.

Orientador: André Frossard Pereira de Lucena

Rio de Janeiro
Dezembro de 2018

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Examinada por:

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Prof. André Frossard Pereira de Lucena, D.Sc.

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Prof. Alexandre Salem Skzlo, D.Sc.

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Prof. Roberto Schaeffer, Ph.D.

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RIO DE JANEIRO, RJ – BRASIL

DEZEMBRO DE 2018

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"Climate change is a member of a special kind of economic activity known as global public goods. To solve this problem, at a minimum, all countries should agree to penalize carbon and other GHG emissions."

William Nordhaus, 2018 Nobel Prize in Economic Sciences

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Resumo da Tese apresentada à COPPE/UFRJ como parte dos requisitos necessários para a obtenção do grau de Doutor em Ciências (D.Sc.)

PROPOSTA DE IMPLEMENTAÇÃO DE UM INSTRUMENTO DE PRECIFICAÇÃO DE CARBONO NA INDÚSTRIA BRASILEIRA: AVALIAÇÃO DOS RISCOS À COMPETITIVIDADE E IMPACTOS DISTRIBUTIVOS

Luan dos Santos

Dezembro/2018

Orientador: André Frossard Pereira de Lucena

Programa: Planejamento Energético

Após a COP 21 e da adoção do Acordo de Paris em dezembro de 2015, as perspectivas para as políticas de precificação de carbono foram ampliadas. Durante a conferência, o Brasil anunciou a meta de reduzir as emissões de GEE em 37% em relação aos níveis de 2005 até 2025 e a intenção de reduzir 43% até 2030. Considerando o setor industrial, não há detalhes nem quantificações precisas. Essa lacuna pode representar uma oportunidade estratégica para implementar um instrumento de precificação de carbono (IPC), como esquemas de comércio de emissões (ETS) ou tributos sobre carbono, neste setor. Dessa forma, esta tese tem como objetivo avaliar desenhos institucionais para o IPC na indústria brasileira, visando reduzir sua vulnerabilidade interna e exposição ao comércio internacional. Para isso, é realizada uma análise qualitativa e quantitativa levando em conta as lições aprendidas a partir da revisão da experiência internacional, além da avaliação dos impactos doa IPCs nas políticas setoriais e a exposição subsetorial ao risco de vazamento de carbono a partir de diferentes metodologias. Os resultados mostram que diferentes desenhos institucionais são melhores ou piores dependendo de seu objetivo principal e do impacto a ser minimizado. Considerando a redução dos efeitos sobre a competitividade setorial e sobre o poder de compra das famílias como variáveis principais, um ETS cobrindo as emissões totais do setor, distribuído por um método de alocação gratuito e baseado em *grandfathering* parece ser uma maneira mais politicamente aceitável de se implementar um IPC na indústria brasileira.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

PROPOSAL FOR THE IMPLEMENTATION OF A CARBON PRICING INSTRUMENT IN THE BRAZILIAN INDUSTRY: ASSESSING COMPETITIVENESS RISKS AND DISTRIBUTIVE IMPACTS

Luan dos Santos

December/2018

Advisor: André Frossard Pereira de Lucena

Program: Energy Planning

After the COP 21 and the adoption of the Paris Agreement in December 2015, the outlook for carbon pricing policies has been widened. During the conference, Brazil has announced a target to reduce its GHG emissions by 37%, compared to 2005 levels, by 2025, and the intention to reduce 43% of such emissions by 2030. However, considering the industrial sector, there are neither details nor precise quantifications. This gap can represent a strategic opportunity to implement carbon pricing instruments (CPI), such as emissions trading schemes (ETS) or carbon taxes, in this sector. Therefore, this thesis aims to assess institutional frameworks for CPI in the Brazilian industry seeking to reduce its domestic vulnerability and international trade exposure. For this purpose, a qualitative and quantitative analysis is carried out taking into account the lessons from a review of the international experience, besides the assessment of the CPI impacts on sectorial policies and the exposure to the risk of carbon leakage scrutinized under different methodologies. Results show that different institutional frameworks are better or worse depending on main objectives and the impacts to be minimized. Considering the reduction of effects on sectorial competitiveness and families' purchasing power as main drivers, an ETS covering total industry emissions, distributed considering a free allocation method and grandfathered-based seems to be a more politically-palatable way to implement a CPI in the Brazilian industry.

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LIST OF ACRONYMS

ABAL	Brazilian Aluminum Association
ABC Plan	National Plan for Low Carbon Emissions in Agriculture
ACCU	Australian Carbon Credit Units
ACPM	Australian Carbon Pricing Mechanism
AFOLU	Agriculture, Forestry, and other Land Use
APCR	Allowance Price Containnment Reserve
BAT	Best Available Technology
BAU	Business As Usual
BC	British Columbia
BEN	National Energy Balance
BM	Benchmarking
BNDES	Brazilian Development Bank
BTA	Border Tax Adjustment
BTM	Border Tax Measures
BVRio	Rio’s Green Stock Exchange
C2ES	Center for Climate and Energy Solution
CARB	California Air Resources Board
CC	Carbon Cost
CCI	CCI – California Climate Investiments
CDM	Clean Development Mechanism
CDP	Carbon Disclosure Project
CEC	California Energy Comission
CER	Certified Emission Reductions

CFI	Carbon Farming Initiative
CGE	Computable General Equilibrium
CH_4	Methane
CIDE	Contribution of Intervention in the Economic Domain
CLL	Carbon Leakage List
CNI	National Industry Confederation
CONAMA	National Council for the Environment
Conpet	National Program for the Rationalization of the Use of Oil and Natural Gas Derivatives
CO_2	Carbon Dioxide
COP	Conference of the Parties
CP	Carbon Pricing
CPA	Carbon Pricing in the Americas
CPI	Carbon Pricing Instruments
CPM	Carbon Pricing Mechanism
CSN	National Steel Company
CVM	Securities and Exchange Commission
EC	Export Coefficient
E&P	Exploration and Production
EII	Energy-Intensive Industries
EIR	Emissions Intensity in Revenue
EITE	Energy-Intensive and Trade-Exposed
EIVA	Emissions Intensity in Value Added
ERF	Emissions Reduction Fund
EU	European Union
EU ETS	European Union Emissions Trading Scheme

ETS	Emissions Trading Scheme
EUA	European Union Allowance
FCE	Free Contracting Environment
FINEP	Financier of Studies and Projects
FSB	Fixed Sector Benchmarks
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GF	Grandfathering
GHG	Greenhouse Gas
GPV	Gross Production Value
GVA	Gross Value Added
GVP	Gross Value of Production
GWP	Global Warming Potential
H	High (risk)
HFC	Hydrofluorocarbon
IAB	Brazil Steel Institute
IAF	Industry Assistance Factor
IBGE	Brazilian Institute of Geography and Statistics
IBRD	International Bank for Reconstruction and Development
ICAP	International Carbon Action Partnership
ICLFS	Integrated Cropland-Livestock-Forestry Systems
ICMS	Tax on Circulation of Goods and Services
IIT	Individual Income Tax
IMF	International Monetary Fund
iNDC	intended Nationally Determined Contributions
INMETRO	National Institute of Metrology, Quality and Technology

IPCC	Intergovernmental Panel on Climate Change
IPI	Tax on Industrialized Products
IPVA	Motor Vehicle Property Tax
IRPF	Individual Income Tax
JI	Joint Implementation
L	Low (risk)
LC	Local Content
LME	London Metal Exchange
LULUCF	Land Use, Land Use Change and Forestry
M	Medium (risk)
MAC	Marginal Abatement Cost
MBRE	Brazilian Emission Reduction Market
MCTIC	(Brazilian) Ministry of Science, Technology, Innovation and Communication
MDIC	(Brazilian) *Ministry* of *Development*, *Industry* and *Foreign Trade*
MF	(Brazilian) Ministry of Finance
MME	(Brazilian) Ministry of Mines and Energy
MoU	Memorandum of Understanding
MRV	Monitoring, Reporting and Verification
N_2O	Nitrous Oxide
NDC	Nationally Determined Contributions
NDRC	(China's) National Development and Reform Commission
NER	New Entrants Reserve
NGO	Non-Governmental Organizations
NPCC	(Brazilian) National Policy on Climate Change
NZU	New Zealand allowance Units
OBA	Output-Based Allocations

OECD	Organisation for Economic Co-operation and Development
PBE	Brazilian Labeling Program
PDE	Ten-Year Energy Plan
PFC	Perfluorocarbons
PM	Particulate Matter
PMR	Partnership for Market Readiness
PNRH	National Water Resources Policy
PNRS	National Solid Waste Policy
Procel	National Electricity Conservation Program
RAIS	Annual Social Information Ratio
R&D	Research and Development
R,D&I	Research, Development and Innovation
RGGI	Regional Grennhouse Gas Initiative
RIA	Regulatory Impact Analysis
SF_6	Sulfur Hexafluoride
SIRENE	National Emissions Registration System
TI	Trade Intensity
TRU	Tables of Resource and Uses
UNFCCC	United Nations Framework Convention on Climate Change
VA	Value Added
WCI	Western Climate Initiative
WTO	World Trade Organization

LIST OF UNITS

AUD	Australian dollar
CO_2	Carbon Dioxide
G	giga = 10^9
k	kilo = 10^3
M	mega = 10^6
MMT	million metric tonnes
Mt CO_2	million tonnes of carbon dioxide equivalents
t	ton
tce	tons of coal equivalent
toe	tons of oil equivalent
US$	American dollars

1. Introduction

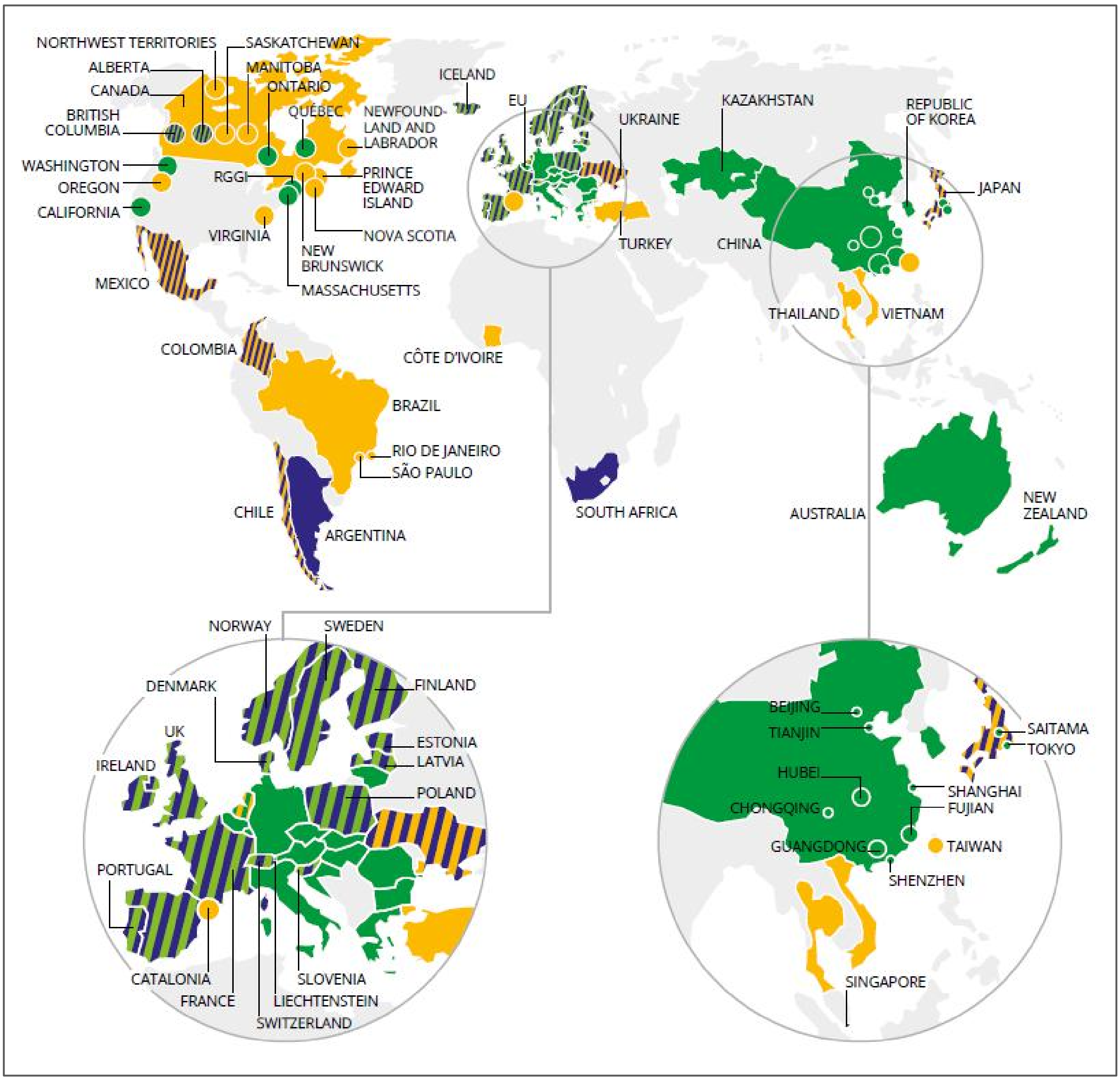
Climate change has been identified as one of the greatest economic and political challenges faced by the world economy (IPCC, 2014). This is due to the need to reconcile the global nature of the problem with action at regional, national and/or local levels (SCHÜTZE et al., 2017; WORLD BANK GROUP, 2016; KNIGHT, 2011). Impacts of climate change have increasingly played a central role in political, economic, social and environmental discussions, since countries, by signaling the transition to a low carbon economy-based development model, are looking for solutions and mechanisms to reduce emissions of greenhouse gases (GHG) that are technically and economically feasible (UNEP, 2017).

With pressure on governments to urgently "decarbonise" the global economy, policy makers have turned to market solutions to reduce the carbon intensity of the economy (ICAP, 2018; PERTHUIS and TROTIGNON, 2014; SEROA DA MOTTA, 2011; HASSELKNIPPE, 2003). In the international discussions, for example, there is a strong debate about alternative policies and instruments that can be used to put a price on carbon and signal to economic agents a development path based on low carbon emissions (WORLD BANK et al., 2018; CPLC, 2016, 2017).

Carbon pricing gives flexibility to sector efforts to reduce GHG emissions, allowing mitigation targets to be achieved more cost-effectively. In addition to being a key component of an effective and efficient mix of climate policies, it also presents itself to the private sector as an important tool for risk management and the development of competitive advantages in a world in transition for decarbonization (CEBDS, 2016).

Policy-makers have at their disposal command-and-control measures and market-based instruments. The later include the commercialization of GHG emissions permits (emissions trading schemes – ETS) and the taxation of emissions (carbon tax) (GVCES, 2013). According to ICAP (2018), WORLD BANK GROUP (2016), and FANKHAUSER, HEPBURN and PARK (2010), determining a price on carbon is fundamental to climate policy, so that different designs of carbon pricing instruments (CPI) are being developed by countries, taking into account national and regional specificities as well as the dynamics of involved sectors. According to experts, the most economically-efficient way to reduce GHG emissions is through the use of CPI (ALDY, 2016; EDENHOFER et al., 2015; METCALF and WEISBACH, 2009; SCHMALENSEE and STAVINS, 2015).

Currently, 45 national and 25 subnational[1] jurisdictions are putting a price on carbon (Figure 1). Carbon pricing initiatives already in place and scheduled for implementation would cover approximately 11 gigatons of carbon dioxide equivalent ($GtCO_2e$), roughly 20% of global emissions, compared to 8 $GtCO_2$ or about 15% in 2017 (WORLD BANK et al., 2018).



Note: ETS implemented or scheduled for implementation; Carbon tax implemented or scheduled for implementation; ETS or carbon tax under consideration; ETS and carbon tax implemented or scheduled; Carbon tax implemented or scheduled, ETS under consideration; ETS implemented or scheduled, carbon tax under consideration

Figure 1 – Summary map of regional, national and subnational carbon pricing initiatives implemented, scheduled for implementation and under consideration

Source: WORLD BANK et al. (2018)

[1] Cities, states and subnational regions.

According to the State and Trends of Carbon Pricing 2018 Report (WORLD BANK et al., 2018), carbon prices vary substantially, from less than US$1/t$CO_2$e to a maximum of US$139/tCO_2e. Also, governments raised approximately US$33 billion in carbon pricing revenues in 2017, the source of which was allowance auctions, direct payments to meet compliance obligations and carbon tax receipts. This represents an increase of nearly US$11 billion compared to the US$22 billion raised in 2016. Figure 2 summarizes these numbers.

Figure 2 – Carbon pricing in numbers

Source: Adapted from WORLD BANK et al. (2018)

With the conclusion of the 21th Conference of the Parties (COP 21) and the adoption of the Paris Agreement in December 2015, the outlook for carbon pricing policies has been widened. While the Agreement does not directly provide for a global carbon price, the provisions set out in Article 6 have the potential to increase international cooperation in favor of mitigation through market mechanisms (CEBDS, 2016). In this context, Nationally Determined Contributions (NDCs) from 88 countries – which represents 56% of global GHG emissions – indicate the interest in using carbon pricing to achieve their goals, as shown in Figure 3 (WORLD BANK et al., 2018). Others also highlight the possibility of reaching emission reductions greater than those declared if it contains access to international market mechanisms (EDF and IETA, 2016; WORLD BANK GROUP, 2016).

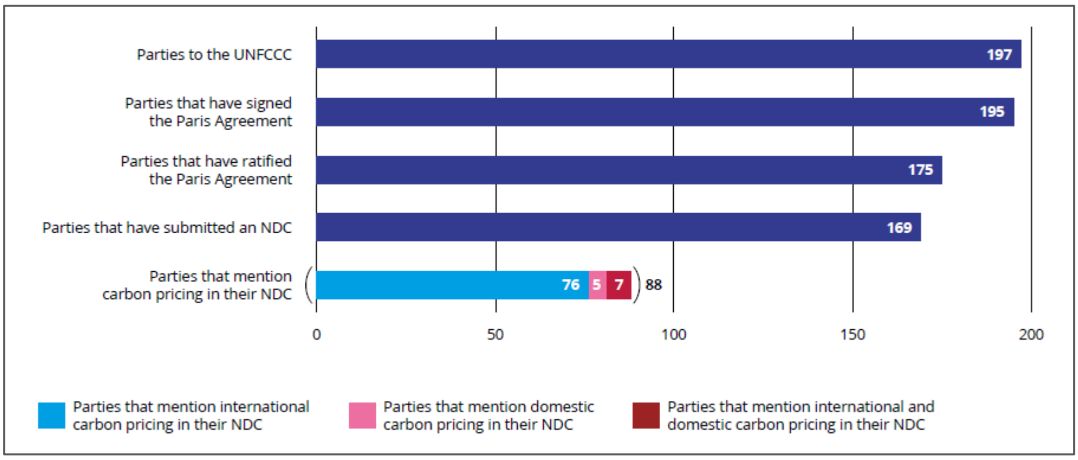
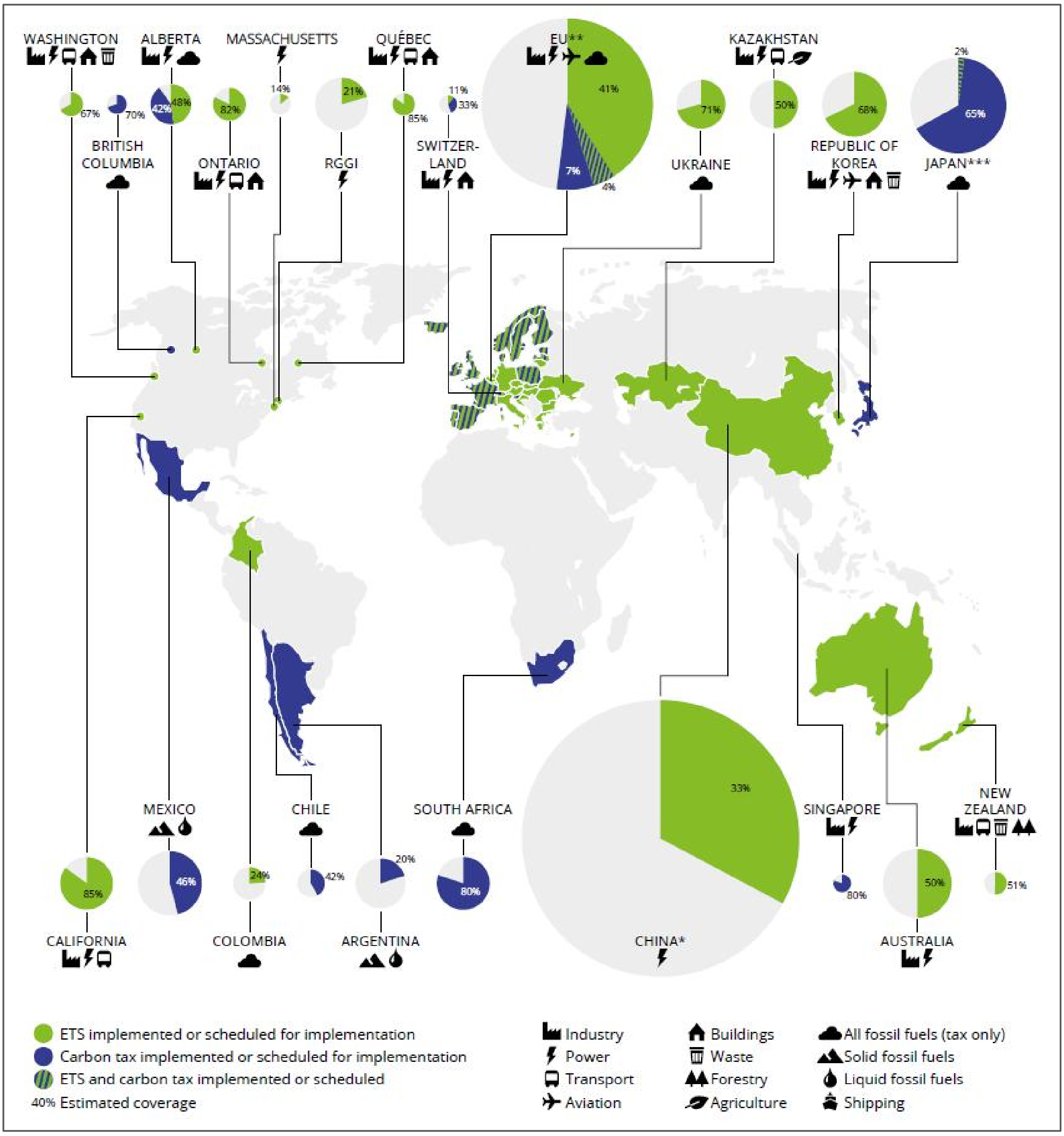


Figure 3 – Status of NDC submissions

Source: WORLD BANK et al. (2018)

The way each country designs and implements carbon pricing is influenced by environmental, economic, social and institutional conditions. Thus, the incentive structures of a CPI vary widely, depending on each country's mitigation strategy. The understanding of the institutional and regulatory framework, therefore, is essential to the economic and distributive results from implementing a CPI.

Also it is important to analyze the sectors covered by the CPI. Energy-intensive industries (EIIs) will continue to play a very important role in low-carbon development, however they are particularly exposed to impacts of carbon pricing policies, and the constraints arising from national climate policies thus are a double-edged sword. On the one hand, steel, cement, aluminum, basic chemicals and pulp and paper represent the classic sectors of industrialization and rising living standards (DROEGE, 2013). Products from these sectors are also an integral part of a low-carbon restructuring of the economy, be it in new energy technologies, in new buildings and insulation projects, or as light materials. On the other hand, these industries often represent some of the largest sources of energy consumptions and GHG emissions and are similarly integral in meeting emissions reduction targets. Figure 4 shows the sectorial coverage and the GHG emissions covered of the carbon pricing initiatives implemented or scheduled for implementation.



Note: The size of the circles reflects the volume of GHG emissions in each jurisdiction. Symbols show the sectors and/or fuels covered under the respective carbon pricing initiatives.
* The coverage includes the China national ETS and seven ETS pilots. The coverage represents early unofficial estimates based on the announcement of China's National Development and Reform Commission on the launch of the national ETS of December 2017 and takes into account the GHG emissions that will be covered under the national ETS and are already covered under the ETS pilots.
** Also includes Norway, Iceland and Liechtenstein. Carbon tax emissions are the emissions covered under various national carbon taxes; the scope varies per tax.
*** ETS emissions are the emissions covered under the Tokyo CaT and Saitama ETS.

Figure 4 – Carbon pricing initiatives implemented or scheduled for implementation, with sectorial coverage and GHG emissions covered

Source: Adapted from WORLD BANK et al. (2018)

Nonetheless, industries often contest the introduction of national emissions pricing due to fierce competition in international markets. Moreover, uncertainties about future demand, costs, technological breakthroughs, and risks related to political frameworks determine firms' investment decisions and other strategic parameters. However, without a carbon price to internalize environmental impacts there will be little incentive to reduce carbon-intensity along the value chain. Giving direction to structural change while avoiding economic decline, and maintaining diversity within and across industries in an economy, is a major challenge for policymakers. This thesis aims to assist the Brazilian industry's policymakers in this process.

1.1. Justifications

From this international context, Brazil has been an important player in the discussions about climate change and its policies (GURGEL and PALTSEV, 2017). During the 15th Conference of the Parties (COP 15), in Copenhagen in 2009, under the United Nations Framework Convention on Climate Change (UNFCCC) coordination, the country assumed a pioneering position among developing countries in terms of commitments to mitigate climate change. It announced volunteer goals to decrease emissions between 36.1% and 38.9% regarding emissions projected for 2020. With the voluntary reduction proposal, the government intended to prevent the country from issuing between 975 million and 1 billion tonnes of carbon dioxide by 2020, compared to forecasting emissions if no action is taken (Business As Usual – BAU).

These objectives agreed at COP 15 gained legal force, following the enactment of Law 12,187, of December 29, 2009, which established the National Policy on Climate Change (NPCC). It promoted the adoption of a voluntary national commitment to reduce projected GHG emissions by 2020 (WORLD BANK, 2011) and was regulated by Decree 7,390, dated December 9, 2010, which regulates some articles of the Law and imposes emission targets for GHG by economic sectors (BRAZIL, 2009, 2010). In its article 5, the NPCC affirms that "the use of financial and economic instruments to promote mitigation and adaptation actions to climate change" will be encouraged, and it is highlighted in article 6 that such mechanisms are among those already existing in the scope of the UNFCCC, which must present environmental standards and measurable and verifiable targets (BRAZIL, 2009).

More recently, the COP 21 held in Paris in 2015 was a milestone in the history of international politics with the adoption of the Paris Agreement (CEBDS, 2017). Driven by long-term visions for development and sustainability, it aims to strengthen the global response to the challenges posed by climate change. To this end, it establishes the goal of limiting the increase in the average temperature of the planet to a level below 2°C in relation to pre-industrial levels, with an indication of efforts so that the limit of 1.5°C is not exceeded (BRAZIL, 2015b).

As part of the agreement, more than 180 countries submitted their intended Nationally Determined Contributions (iNDCs). Many of these have now become formalized as NDCs for all 177 countries that have ratified the agreement[2]. For the first time in the history of international negotiations on climate change, the vast majority of developing countries took quantified pledges to contain the growth of, or even reduce, their absolute domestic GHG emissions.

Brazil has announced the target of reducing GHG emissions by 37% compared to 2005 levels by 2025 and the intention to reduce 43% by 2030. Several indicative mitigation strategies were envisioned and explicitly described in the Brazilian NDC to be achieved by 2030 (GURGEL and PALTSEV, 2017; MCTI, 2016a). These include (BRAZIL, 2015a,b): achieve zero illegal deforestation; restoring and reforesting 12 million hectares (ha) of forests; increasing the share of sustainable biofuels in the energy mix to 18%; achieving 45% of renewables energy sources in the energy mix; increasing the share of renewables in the power supply to 23%; achieving efficiency gains of 10% in the electricity sector; restoring 15 million ha of degraded pastures, and; expanding the area of integrated cropland-livestock-forestry systems by 5 million ha.

Brazilian NDC also considers the use of market mechanisms, although there is no indication as to how these instruments will be used. According to the text, the country reserves its position on the possibility of using the mechanisms that may be established under the Paris Agreement (BRAZIL, 2015b). However, although NDC does not describe how or whether carbon will be priced in Brazil, studies to evaluate possible CPI impacts in the country have been considered by the federal government at least since 2011, when the country submitted its application to the Partnership for Market Readiness (PMR), a program administered by the World Bank, whose main objective is to support the preparation and implementation of carbon pricing in developing countries (MF, 2014; CEBDS, 2016). Discussions about its design and implementation have reached a new level in the last years (CEBDS, 2016).

[2] Until October 2nd 2018, based on UNFCCC website. Source: https://unfccc.int/process/the-paris-agreement/nationally-determined-contributions/ndc-registry.

As mentioned before, the Brazilian NDC quantifies some specific measures, such as reforestation and increase in the share of bioenergy in the Brazilian energy system. However, regarding the industrial sector, there are neither details nor precise quantifications. Brazil's NDC only mentions that "the industrial sector should promote mitigation actions based on new clean technologies standards, energy efficiency measures and low carbon infrastructure" (BRAZIL, 2015a, b).

One can verify a vague and comprehensive nature of the Brazilian NDC, which makes it difficult to measure the low emission efforts to be directed to the industrial sector, as well as potential results of the measures adopted. On the other hand, NDC's generality makes it possible to consider the various mitigation opportunities, especially when considering the heterogeneity of the national industry sector.

It has a high degree of economic linkage with other sectors and is highly sensitive to macroeconomic policies (EPE, 2016; BARROS and GUILHOTO, 2014). In spite of the relative contraction of the sector in the last decades, the industry maintains its relevance to the national economy: in 2015, industry accounted for 15.7% of jobs in the country and 38.1% of national exports (CNI, 2015).

However, there is no coherent framework of measures and policies to requalify and sustain a new growth cycle in the Brazilian industrial sector (CEBDS, 2016). Such a gap becomes more relevant in the context of the consolidation of the low carbon economy, in which new competitiveness variables, such as energy and carbon intensity, can create unprecedented pressures for the sector. Especially considering the industry sector emissions, if in recent decades Brazilian industry has been losing its position in the national economy, its GHG emissions have gained importance as deforestation have fallen in Brazil[3]: in 1990, the industrial sector was responsible for 8.5% of emissions (including fuel combustion and industrial processes), while in 2010 it was 22.6%, according to the Third Brazilian Inventory of Anthropogenic Greenhouse Gas Emissions and Removals (MCTI, 2015).

Nevertheless, a recently Brazilian study published on Nature Climate Change this year (2018) points out that the Brazilian government is indicating to the landholders to increase deforestation, putting the country's contribution to the Paris Agreement at risk (ROCHEDO et

[3] Participation in net CO_2 emissions from Land Use, Land Use Change and Forestry (LULUCF) reduced from 83.4% in 2005 to 42% in 2010 (MCTI, 2015).

al., 2018). The risk of reversals of recent trends in deforestation governance could impose a burden on other sectors (for instance, industrial sector) that would need to deploy not yet mature technologies to compensate for higher emissions from land-use change. As a result, it sheds light on the need to address GHG mitigation in the industrial sector.

Thus, incentives for efficiency and processes innovations (R&D), new financing instruments, implementing specific regulatory instruments – such as a carbon pricing – and establishing technological standards are key drivers for the development of a low carbon industrial sector in Brazil (CEBDS, 2017, CEBDS, 2016). Nevertheless, other challenges also exist in this sector, such as high costs and the incipient stage of some technologies (PINTO et al., 2018; HENRIQUES, DANTAS and SCHAEFFER, 2010), the need for adaptability of these technologies to the Brazilian plants and the difficulty to obtain cheap loans and financing (CEBDS, 2017).

Despite not detailing strategies for the industrial sector, the current Brazilian climate policy is still uncertain in terms of mechanisms and economic instruments for carbon pricing. Although there are a number of studies that analyze the economic impacts on the Brazilian industry from the implementation of CPIs, considering ETS, carbon tax or hybrid systems (GRAMKOW and ANGER-KRAAVI, 2018; PINTO et al., 2018; GURGEL and PALTSEV, 2017; FIESP, 2017; MCTI, 2016; LUCENA et al., 2016; OCTAVIANO et al., 2016; MAGALHÃES et al., 2015; INSTITUTO ESCOLHAS, 2015; WILLS and GROTERRA, 2015; SANTOS, 2014; CASTRO and SEROA DA MOTTA, 2014; WILLS, 2013; RATHMANN, 2012; SILVA and GURGEL, 2012; WILLS and LEVEFRE, 2012; HENRIQUES et al., 2010), there is a gap with regard to more focused studies in analyzing these impacts considering different policy and instrument designs.

In this context, it is also important to assess how such instruments would interact with other existing policies, such as commercial and tax policies. Given the national context, understanding how the different CPI configurations impact the industry is even more necessary at the present moment, in which the Brazilian Ministry of Finance (MF) is analyzing which instrument(s) will be adopted in Brazil after 2020 in the context of the PMR project. Still in this context, the Brazilian Market Readiness Proposal (MRP) is currently being developed and it is divided into some phases whose main objective is to develop sectorial studies to investigate the main issues involved in implementing CPI in the economic sectors/subsectors. The results of these studies will guide the following activities that will evaluate the quantitative impacts of the instruments proposed using a Computable General Equilibrium (CGE) model.

At the same time, it is also necessary to analyze the CPI's impacts on sectorial GDP, competitiveness indicators, international trade and commercial balance, besides considering indirect impacts on other economic sectors, given the intersectorial connections. Theses aspects also configure a relevant lack in the literature and therefore should be properly analyzed. It is widely recognized that the problem of carbon leakage poses a major challenge for designing effective unilateral policies aimed at mitigating global climate change. Carbon leakage could be defined as the displacement of emissions from a jurisdiction to another one, due to asymmetrical climate policies, resulting in same, or higher, volume of global emissions (MARCU et al., 2014). Asymmetrical climate policies are understood as policies that impose carbon constraints in one jurisdiction, while other ones have less stringent, or no, carbon constraints. In addition, carbon leakage creates an excess burden for those countries that regulate emissions to the extent that relocation reduces output, employment, and taxable profits at home (MARTIN et al., 2014).

Not surprisingly, carbon leakage takes the center stage whenever a new climate change regulation is up for debate. This could be seen in the different international experiences existing, for example in Europe, Australia, California, South Africa, China, Chile, Mexico, among other regions. Such experiences used different methodologies to analyze the possible impacts on the national industry, varying from indicators like carbon cost, emissions intensity, trade intensity, among others (EUROPEAN COMISSION, 2014; EUROPEAN PARLIAMENT AND COUNCIL, 2009; CARB, 2012; CALIFORNIA CODE OF REGULATIONS, 2011; DECCEE, 2011a, 2012). Not unlike that, the assessment of carbon leakage in the Brazilian industry also needs to be evaluated in the context of the CPI implementation. This assessment will identify which sector(s) is/are most prone to carbon leakage risk, and thus mitigating policies and measures can be developed to reduce such impacts.

The primary benefit of a well-designed competitiveness policy is that it would mitigate and potentially eliminate the competitiveness risks. Nonetheless, competitiveness policies also carry risks, in terms of their potential impacts on the distribution of the benefits and costs of carbon pricing policy, the efficiency of pricing carbon, and international relations in multilateral trade and climate policy contexts.

As a matter of fact, most carbon pricing policies include provisions to compensate regulated sectors for the cost of compliance (SATO et al., 2015). They could impose tariffs reflecting the embedded carbon emissions in imports, such that domestically produced goods and their foreign competitors face a common carbon price (WEISBACH, 2015; AGAN et al. 2015). Climate policy could direct benefits to potentially vulnerable firms, such as through free allowance allocations in cap-and-trade programs or targeted tax credits (GRAY and METCALF, 2015). Some northern European carbon tax programs have explicitly exempted energy-intensive manufacturing from their carbon tax (ALDY and STAVINS, 2012). Policymakers could work through multilateral negotiations to ensure that major trade partners undertake comparable domestic emissions mitigation policies. They could take such multilateral coordination a step further by linking domestic mitigation programs among trade partners, which could then yield a common carbon price for businesses operating under all linked programs.

These policy options, however, carry their own risks. They may run afoul of current obligations under the World Trade Organization – WTO (TRACHTMAN, 2015). The design of such policies may result in a loss in social welfare and limit the ability of the government to offset potentially regressive impacts of pricing carbon. Competitiveness policies may also have important implications for ongoing international climate negotiations. Finally, the choice and design of competitiveness policies may entail political risks that could also weaken support for the broader domestic climate change policy program.

1.2. Objectives

This thesis has a general objective, which can be deployed in some specific objectives. These objectives are detailed below.

1.2.1. General Objective

The general objective of this thesis is to propose an institutional framework for carbon pricing instrument (CPI) for the Brazilian industry aiming to reduce its domestic vulnerability and international trade exposure.

1.2.2. Specific Objectives

The specific objectives of this thesis are:

- Analyzing the functionality and impacts of the various CPIs given the adoption of different possible designs;
- Evaluating international experiences to extract lessons learned in order to design the CPI in the Brazilian industry;
- Assessing the competitiveness risks and mitigation policies to avoid carbon leakage;
- Analyzing and comparing the methodologies and the quantitative assessment criteria to address domestic vulnerability and international trade exposure from the CPI adoption;
- Understanding the Brazilian climate policy and the current national discussions about CPI implementation;
- Analyzing the Brazilian industrial sector, in terms of economic characterization, sectorial emissions profile, and existing sectorial policies;
- Identifying the Brazilian industrial sectors under carbon leakage risk;
- Analyzing the Brazilian industrial sector interaction with other sectors, such as fuel, power sector and Agriculture, Forestry and Other Land Use (AFOLU); and
- Proposing institutional frameworks for the Brazilian industry CPI.

1.3. Thesis Structure

In order to achieve these objectives, this thesis is structured as follows. This current chapter (Chapter 1) introduces the topic, presenting its justification, relevance, general and specific objectives, besides the thesis structure. Chapter 2 focuses its analysis on defining and designing climate policies and their instruments, also assessing lessons learned from the main international experiences, and addressing competitiveness risks and mitigation policies for carbon leakage. Chapter 3 evaluates the Brazilian climate policy and concentrates its assessments on the industrial sector, focusing on the economic characterization, emissions profile and existing sectorial policies. Chapter 4 performs both a qualitative and quantitative analysis in order to assess the interactions between sectorial polices and different CPI designs, besides evaluating the international methodologies and criteria to address domestic vulnerability and international trade exposure of industry. This chapter also applies these methodologies and indicators in the Brazilian industry sector with the purpose to identify the most exposed subsectors to carbon leakage. Chapter 5 aims to propose institutional frameworks for the Brazilian industry's CPI, defining and comparing the different alternatives, besides proposing a particular configuration for CPI in the Brazilian industry. Finally, chapter 6 presents the main conclusions, recommendations, limitations of the thesis and perspectives for future researches. References and three annexes are also presented. Figure 5 visually summarizes this thesis structure.

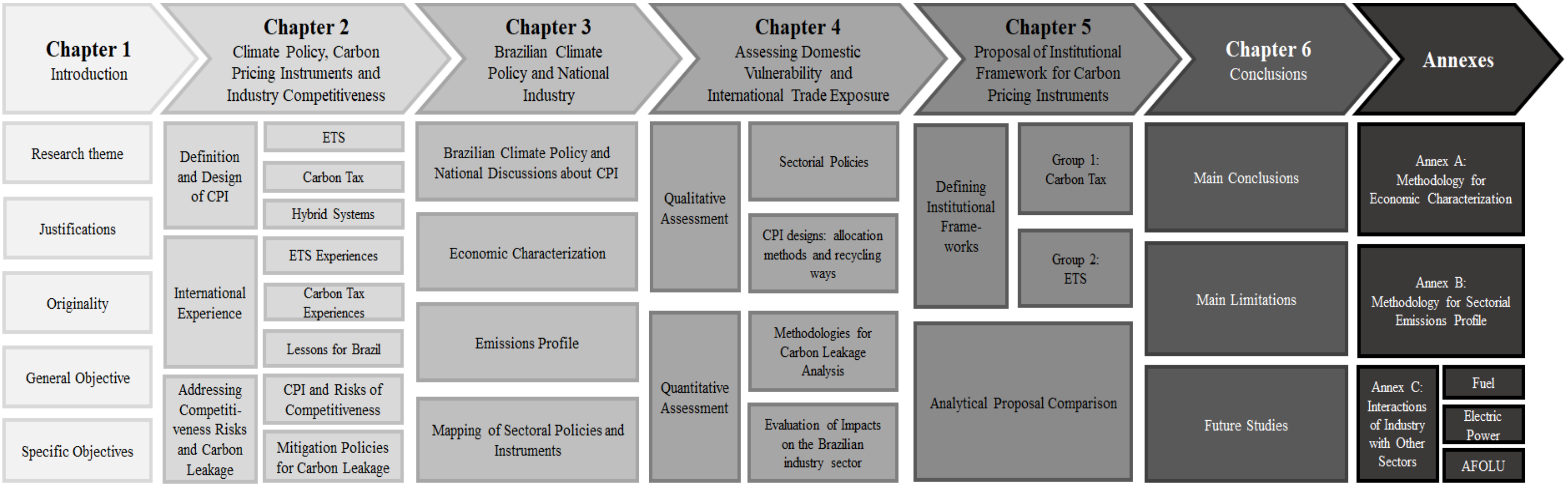


Figure 5 – Thesis structure
Source: Own elaboration

2. Climate Policy, Carbon Pricing Instruments and Industry Competitiveness

Different instruments have been developed and used to reduce the impacts of climate change. When analyzing the international experience, there is a growing adoption of economic instruments at its most diverse levels (national, state, city, etc.), among which we can highlight the use of a carbon tax, a carbon market or even hybrid mechanisms. However, numerous issues emerge regarding economic and political impacts in terms of eventual loss of competitiveness and the need to develop policies to mitigate such impacts.

This chapter is divided into three sections. The first one aims to define and discuss the main economic instruments of climate policy, assessing their associated opportunities and challanges. The second one holds a brief debate on the main international experiences, aiming to highlight the most relevant lessons learned. The third one examines risks to competitiveness, as well as identifing and evaluating the mitigation policies of carbon leakage.

2.1. Definition and Design of Climate Policies and their Instruments

Considering the (monetary) internalization of externalities via market as the main object in the study of environmental and climate policies, ALIER and SCHULÜPMAN (1998) mention two fundamental aspects that must be taken into account: how to value external costs and which environmental policy instruments should be used to achieve the optimal level of pollution (social optimum). In this sense, the classic environmental policy instruments can be classified either as command-and-control (mandatory) or market (incentives) instruments, mainly based on economic instruments. The main differences between them are their cost-effectiveness, costs associated with monitoring, equity and distribution, flexibility and level of information required (WORLD BANK et al., 2018; SEROA DA MOTTA, 2011; IPCC, 1996, PERMAN et al., 1996; PEARCE e TURNER, 1989).

Economic instruments are characterized as cost-effective when compared to command-and-control instruments, since they reach the environmental goal at the lowest social cost, given by the equalization of the marginal abatement cost among the different firms (ICAP, 2018, CRAMPTON et al., 2017, NARASSIMHAN et al., 2017). Economic instruments affect the costs and benefits of activities, influencing the decision-making process, improving environmental quality (RATHMANN, 2012). Compared to command-and-control mechanisms – like technological, efficieny and emissions standards – economic instruments provide flexibility to pollutants to choose the best economic alternative to achieve the objectives of improving environmental quality and their timing (PERMAN et al., 1996, THOMAS and CALLAN, 2010).

There are some market instruments, among them we can highlight carbon pricing mechanisms. They are based on the polluter pays principle, which defines responsibility and establishes a cost for GHG emissions, internalizing the negative externality. This principle can be implemented through fiscal policies – for instance, by a carbon tax – or by establishing a carbon market or a pollution trading system, better known as emission trading schemes (ETS).

By assigning a price to GHG emissions through a carbon tax, an ETS or even a hybrid mechanism, firms are encouraged to change their production processes in order to reduce their emissions per unit of output. These policies also affect consumer decisions, because rising prices of carbon-intensive goods encourage changes in consumption patterns toward less carbon-intensive goods.

Each carbon pricing mechanism has strengths and weaknesses; each one of them works well in some respects and fails in others. For these reasons, each CPI will be briefly described, presenting their major features in terms of opportunities and challenges when designing mechanisms for implementing carbon policy.

2.1.1. Emission Trading Schemes (ETS)

This instrument originated from the analysis of economist J. H. Dales, who attributed the existence of externalities to the absence or mis-definition of property rights over goods. This discussion refers to the classic Coase Theorem (1960), which states that, in perfect competition, with no or negligible transaction costs, economic agents, through bilateral negotiation and without State intervention, arrive at the efficient solution of the elimination of the social externality problem, regardless of the initial distribution of property rights (PEARCE and TURNER, 1989; PERMAN *et al.*, 1996).

According to DALES (1968), property rights must be exclusive and transferable in order to allow mercantile exchange. It is, therefore, a way of internalizing the externality, whose roots can be traced back to poor property rights. Thus, the author seeks to define such rights to allow their exchange between agents, resulting in the definition of an equilibrium price that fulfills every requirement for a great Paretian.

They operate as follows (FAUCHEUX and NOËL, 1995): the State, or the control body, decides beforehand on the amount of pollution acceptable in the environment and distributes or puts up for sale the pollution rights in the securities market. Each holder of these securities or certificates shall therefore be entitled to issue a quantity of pollution corresponding to the amount of securities held. The difference, in case it pollutes more than the allowable considering the total of licenses owned, should be abated (depollute).

In summary, this allowance market operates in the cap-and-trade format, that is, it sets a standard (cap), divides it into licenses, what gives every player a "right" to pollute, and then a sale of these licenses takes place (trade). Given this scenario, the companies will decide how to act in this market, according to the confrontation between the marginal abatement cost (MAC) and the price of the licenses (PEARCE e TURNER, 1989; FAUCHEUX e NOËL, 1995; PERMAN *et al.*, 1996).

This instrument consists of an organized market where the rights to pollute the environment are allowed to be bought and sold, prices vary according to the forces of supply and demand, allowing individuals to act in accordance with their private interests (FIELD and FIELD, 2002). The total number of allowances will be defined based on a safe amount of emissions that can be "released" into the environment.

Allocation of licenses for marketing is a critical element of the cap-and-trade mechanism, as it promotes the emergence of a single market price for emissions by all market participants (GOULDER and SCHEIN, 2013). This issue has implications on the distributional impacts of the costs and benefits generated by this policy and should therefore be duly analyzed. Also, the choice of sectors to be regulated is directly related to the allocation method of the permits, which can be distributed free of charge – through the grandfathering (GF) or benchmarking (BM) –, auctioned, or regulated by a combination of both methods. Therefore, the question is to discover, in terms of efficiency, what players should receive the rights and how they should be distributed. Thus, this is an eminently distributive issue (PHYLIPSEN et al., 2006; OECD, 2009; IEA, 2010; CASTRO, 2013).

If the free allocation system is chosen, it is necessary to determine the distribution criterion of these allowances. Historical emissions, production level or other pre-set standard can be used to define this distribution pattern (IEA, 2010). This form of distribution reduces the costs of the program to the regulated sectors, since they receive an asset free of charge, besides eliminating the costs added to the firms, without any implication in the efficiency of the program and with clear political advantages (BAUMOL and OATES, 1988). Traditionally, it has been the form adopted by the markets that begin their operations, as will be verified in the upcoming analysis of the international experiences (Section 2.2.).

In the GF case, past emissions are generally used to define future needs for certificates, so that their proper functioning depends on consistent data. However, this system, by using historical emissions, ends up compensating inefficient sectors with more certificates (UK ETG, 2005; IEA, 2010). In addition, companies entering the market will need new allocation criteria, as they also consider in their strategies the free right to part of their emissions. For this reason, special attention should be given to the issue of reservations to incoming companies and how to deal with those who have closed their activities (IEA, 2010).

In the BM free allocation system, the determination of the number of certificates is based on a measure of performance for a given group, usually tCO_2e per quantity produced. Theoretically, this criterion is fairer, since it considers the efficiency of the participants. However, it shows great difficulty in establishing its value (UK ETG, 2005). Thus, this method is rather aligned with the future needs of the actors. Nevertheless, it requires equal treatment for similar facilities. To this end, it is necessary to determine BMs for each type of product or production process, which in turn can make the process more expensive and difficult due to the heterogeneity of products. Moreover, this choice may favor some specific technological route and require the regulator's technical knowledge regarding the processes, products and raw materials (UK ETG, 2005; CASTRO, 2013).

Certificates can also be sold by the regulator through auctions. In this system, regulated sectors face additional costs since the beginning of the program (BAUMOL and OATES, 1988). With regard to efficiency and environmental effectiveness, some authors believe that this is the most desired method. That is because it is the most direct way of revealing market prices, reducing the political pressures of specific groups, and dividing the costs of regulation between regulated and regulatory agents (CRAMTON and KERR, 2002, OECD, 2006), in addition to generating revenues that can be used by the state to mitigate the impacts of the instrument through different recycling methods. In this approach, it is not up to the regulator to calculate the need for each participant in the program; it is the regulated agents themselves who must formulate their projections and their abatement costs.

In general, free allocation methods, especially the GF, have been used due to less opposition from regulated institutions to this system. For CRAMTON and KERR (2002), the distribution via auctions reduces distortions, provides greater incentives for innovation and offers more flexibility in the distribution of costs. However, even though this method is theoretically more efficient, politically free allocation is more feasible. Another argument strongly used by the economic sectors that justifies the free allocation of licenses is the possibility of competitiveness loss in the international market and carbon leakage, given an eventual charge for the licenses, what would change the final price of the goods offered. In practice, it is observed that the free distribution, whether by GF or BM, requires from the regulator more information than the distribution through auctions.

As pointed out by GOULDER and SCHEIN (2013) in the article “Carbon Taxes vs. Cap-and-Trade: A Critical Review”, there is a concern sometimes raised against the cap-and-trade over free allocation, stating that it eliminates the incentive to reduce GHG emissions. According to the authors, the practice suggests the opposite, that is, even when licenses are granted for free, each additional unit of emissions carries an opportunity cost: an additional unit of pollution, or it reduces the number of licenses the company can sell or it increases the number of licenses the company must buy to keep its previous baseline.

However, it is important to emphasize that free distribution of licenses should take into account future entrants into this market, so a new entrants’ reserve (NER) should be established. The size of the NER usually depends on the growth expectations of the various sectors. It is also worth noting that in case the allocation is free for new entrants, this should be based on benchmarking (BM), since activity levels cannot be derived from historical levels.

In general, the initial allocation of licenses, while not affecting the efficiency conditions, generates distributional effects and can therefore be justified by policy objectives that have this purpose. Therefore, the quantity of allowances allocated free of charge affects the amount of such transfer. However, when analyzing the international experiences of the carbon market, it is observed that such markets generally start from the free allocation of the licenses and, little by little, auctions start having a bigger role in the distribution of emission certificates (ICAP, 2018; WORLD BANK et al., 2018; QUIRION *et al.*, 2012; CRAMTON and KERR, 2002).

From the previous discussions, some issues should be analyzed and assessed when desiging an ETS. These steps involve deciding the scope, setting the cap, distributing allowances, considering the use of offsets, deciding on temporal flexibility, addressing price predictability and cost containment, ensuring compliance and oversight, engaging stakeholders, considering linking, and defining an implementation and evaluation process. Table 1 sumarizes these key elements to be considered when developing an ETS:

Table 1 – Key elements for designing an ETS
Source: Own elaboration based on ICAP (2018) and PMR and ICAP (2016)

Features	Considerations and Assessments
Scope Definition	Establish sectors subject to regulation (e.g, industry, buildings, energy, transport), the GHGs included in the policy (e.g, CO_2, CH_4, N_2O, HFCs, SF_6), regulation points (upstream, where the regulation falls on the point of production/commercialization of the emission-generating fuel or downstream, in which the regulation is carried out on the entity or installation responsible for the emission), and the regulatory facilities.
Cap Definition	The cap should be established based on emissions data – historical or projected – from convered sectors. Obtaining the data can follow a top-down or bottom-up approach. It should consider possible trade-offs between cap setting level and regulation costs. It is also necessary to define the trajectory to be followed by the cap that can evolve in absolute or in intensity terms.
Allowances Allocation	Allowances can be allocated free of charge (according to grandfathering or benchmarking criteria) or sold at auctions. The design of the instrument should also predict how the regulation of new entrants, closure of installations and removals of GHG emissions will take place.
Offset Use	If offset of sectors not covered by the ETS and/or credits from emissions reductions achieved in other jurisdictions are accepted, sectors, gases and eligible activities should be defined. The limit on the use of offsets should also be established and there must have a system for governance and monitoring, reporting and verification (MRV).
Temporal Flexibility	It is necessary to define whether the permissions of an installation that have not been used in an ETS compliance phase may be used in future periods (banking) or whether future phase permissions can be used in advance (borrowing), as well as the rules of that mechanism of flexibility. It is also necessary to define the instrument's reporting and compliance periods.
Price Limits	Criteria and methods should be foreseen and designed to intervene on prices if they reach very low or very high levels, rendering the instrument unworkable and inefficient. It is also important to choose the appropriate instrument for marketing intervention, and decide on governance framework.
Compliance and Oversight	The report must be managed by regulated entities. This should comprehend the definition of how the ETS registration will work and how market regulation will be fundamental, as well as how compliance with the regulation will be ensured.
Stakeholder Engajament and Capacity-Building	In addition to identifying the main stakeholders, their interests and concerns, it is necessary to define the strategies for engaging them. It is also important to define the approach to develop capacity building of the actors involved.
Linking with Other Markets	It is necessary to define and design the possibility of linking the ETS with other markets, be it at the regional, national or international level, considering the need for compatibility of the systems, as well as the definition of the partner markets and the type of interconnection to be developed.
Implementation, Revision and Evaluation	An implementation schedule should be defined taking into account the scope of well-defined reviews. It is still important to consider ways of assessing ETS performance and impacts.

2.1.2. Carbon Tax

Many economists advocate a particular type of intervention through a tax on polluters in order to estimate the damage caused (negative externality). Arthur C. Pigou, in Economics of Welfare, proposed a rate as an appropriate way to equate private cost with social cost (PIGOU, 1932). The internalization of externalities for Pigou would occur through the payment of a fee, whose amount would equal the difference between the social cost and the private cost (FAUCHEUX and NOËL, 1995). The internalization of externalities would thus be translated into a payment that would somehow attribute a price to the harmfulness. The price of the good produced would then be equal to the social marginal cost of the good (private cost plus tax).

Imposing a tax on the externality-generating good can correct the externality. If the tax rate is set equal to marginal external damage (the total harm to parties other than the buyer and seller from one additional unit of the good), it brings that external cost into the transaction, ensuring that the buyer pays the full marginal social cost of the good (WILLIAMS III, 2016). Thus, the incentive provided by the tax ensures that the market produces the efficient level of the good (in the absence of any other uncorrected market failures).

The carbon tax is the most direct form of carbon pricing, which establishes the price to be paid for the emission of one unit of GHG. This is usually quantified as a $ price per ton of carbon dioxide or CO_2 equivalent. A carbon tax can be applied either to specific sectors or the entire economy. Once the tax base has been defined, an efficient tax rate takes into account two economic considerations. First, if the primary goal of the tax is to achieve a target of emissions reductions, the level of the tax should be aligned to the marginal cost of the reduction. Second, to ensure consistency across sectors, the carbon tax should reflect the specific carbon content of different fuels that can be used for the same purpose (heating, transportation, industrial processes, etc.).

According to FIELD and FIELD (2002), the definition of the optimum rate is extremely complex. Thus, after conducting modeling studies to find the ideal value for the carbon tax, they propose that the value of this tax should be assumed and then it should be checked the effect caused to the environmental quality. If the environmental quality has not grown in the desired total, the tax must be increased; otherwise, it should be reduced. Through this process of trial and error (learning-by-doing) is that we will reach the optimal carbon tax.

WILLIAM III (2016) also affirms that, in practice, imposing a theoretically ideal tax can be challenging. Estimating marginal damage is difficult, particularly in cases where the harm will occur in the future (as with GHG emissions) or where damage varies widely across space or time (as with local air pollutants). In many cases, it is difficult for taxing authorities to directly measure emissions, and thus imposing the tax on some proxy for emissions (such as the amount of fuel burned) makes it much easier to enforce. In such cases, any tax will need to depart from the theoretical ideal, but the theory provides some general principles: set tax rates based on the best estimate of marginal damage, and when it is impractical to tax emissions directly, choose a proxy that is as close as practicable to what matters for marginal damage (PMR, 2017). Taxing based on those principles will most efficiently correct the negative externality from pollution.

By itself, a carbon tax is likely to slightly slow economic growth. Fossil fuels are used throughout the economy, and thus taxing carbon acts as an implicit tax on all production. This lowers the return to factors of production such as capital and labor (either directly, though effects on wages and profits, or indirectly, by raising product prices and lowering real returns), and it discourages labor, saving, and investment. Furthermore, it is natural to think that a carbon tax will be quite regressive (WILLIAMS, 2016). Its most obvious effect is to raise the prices that consumers pay for direct energy goods: electricity, natural gas, gasoline, heating oil, etc. These goods represent a larger budget share in poorer households than in wealthier ones.

However, one of the main advantages of using carbon taxes is to allow the generation of tax and tariff revenue – equivalent to the situation of an ETS with an auction. That is, such a policy is considered a double-dividend, since in addition to environmental improvement, it generates revenues for regulatory agencies (MAY, 2010; PEARCE e TURNER, 1989; PERMAN et al., 1996). That revenue can be used to cut (or prevent increasing) other taxes, to reduce the budget deficit, to pay for public goods, to address distributional goals, or for many other purposes (PMR, 2017; WILLIAMS III, 2016). At the same time, interactions between environmental taxes and other preexisting taxes (primarily income and payroll taxes) can significantly raise the efficiency costs of environmental taxes (or any other excise tax or similar policy).

The argument that the revenue-raising role of environmental taxes is a substantial additional reason to implement such taxes first came to prominence in the “double dividend” literature (OATES, 1995; REPETTO et al., 1992; PEARCE, 1991; TULLOCK, 1967). The idea is simple: if revenue from an environmental tax can be used to finance a cut in the tax rate for a preexisting distortionary tax (such as the income tax), that cut produces an efficiency gain in addition to the other effects of the environmental tax. The term “double dividend” refers to the assertion that environmental taxes raise economic efficiency through two separate channels, both by correcting an externality and by raising revenue that can be used to cut other taxes. That second “dividend” has since come to be known as the “revenue-recycling effect” (GOULDER, 1995), and this basic concept also envisages different ways of using the revenue: spending the revenue on public goods or using it to cut the budget deficit could produce similar gains in economic efficiency.

In a perfect world, carbon emissions would be taxed worldwide where emissions occur (METCALF, 2017). Restricting our attention to carbon dioxide emissions from fossil fuels, we could also tax fossil fuels upon extraction, since the emissions that will result from the use of those fuels are known. In the real world, carbon emissions are taxed at different rates or not subject to a meaningful price in different countries. This gives rise to leakage and competitiveness issues. Leakage refers to the shifting of production activities from countries that price emissions to those countries that do not. As KORTUM and WEISBACH (2017) point out, leakage reduces global welfare to the extent that production location decisions are distorted by the differential carbon pricing. It also leads to incomplete internalization of the GHG externality.

KORTUM and WEISBACH (2017) also distinguish between leakage and competitiveness concerns. Competitiveness concerns are often raised with respect to firms in energy-intensive, trade-exposed (EITE) sectors. While a unilateral carbon tax without any border tax adjustments (BTA) reduces the competitiveness of EITE firms, the authors note that the tax increases the competitiveness of firms in non-energy-intensive sectors such that the overall competitiveness of firms in a country with a carbon tax is unaffected.

In this sense, BTA aims to apply a carbon tax to imported carbon and rebate the tax on exported carbon. The use of border adjustments shifts the tax from the location of the production of the fossil fuels to the location of the consumption of the goods and services on the basis of the carbon embodied in those goods and services (PMR, 2017). Perfectly applied border adjustments would eliminate leakage concerns.

Key design considerations for a carbon tax system includes choosing the appropriate price, emissions coverage, the point of taxation (upstream or downstream), stringency (i.e., planned escalation of price over time), the flexibility of the price to change in light of new information on marginal cost of abatement, allocation of revenue generated from the tax towards general public spending or specific emissions-reducing activities, and harmonization across boundaries beyond the jurisdiction of the tax. Table 2 sumarizes the key elements to be considered when developing a carbon tax:

Table 2 – Key elements for designing a carbon tax
Source: Own elaboration based on PMR (2017)

Features	Considerations and Assessments
Scope Definition	It corresponds to the selection of the sectors that will be regulated by the tribute, being, generally, those that consume substantially fossil fuels or that are highly intensive in emissions. Also it is important to decide which gases to cover and to choose the points of regulation, besides the entities to regulate and set thresholds.
Calculation Basis and Tax Rate	Generally, the aliquot is calculated based on the CO_2 emissions per unit of fuel burned, using specific emission factors for each fuel, so the aliquot varies according to the carbon content. In addition, aliquots may vary for more or less emission-intensive sectors. Some carbon tax policies provide for gradual rate increase plans, allowing covered entities to adapt financially and technologically. It is important to determine the basis for setting the tax rate, how the rate will develop over time and to consider using modeling to predict the effects of different tax rates on meeting policy objectives.
Potential Undesirable Effects	Assess the risk of the tax leading to carbon leakage or producing negative distributional effects, considering the costs and benefits of adopting measures to mitigate risks and developing criteria to determine eligibility for assistance measures. For example, rebates and exemptions tend to be granted to sectors most exposed to the international market or to those already regulated by some ETS scheme. They can be transient – in order to allow companies to adapt to the new tribute – or permanent, avoiding the loss of competitiveness in some sectors of industry.
Recycling Methods	There is a number of options on how to recycle revenue from tax collection. In some cases, they turn to the population, others to the sectors most vulnerable to the adverse effects of taxation or the financing of environmental measures. There are cases where the revenues are directed to the state coffers and can be used to reduce taxes on income or applied in specific sectors such as education and/or health. It is important to calculate projected revenue from the carbon tax and decide whether to allow offsets.
Legal and Institutional Framework	The policy implemented needs to be transparent and concise in order to be well accepted by the sectors covered by taxation as well as by the population. Frequently, the introduction of a tribute implies a comprehensive reform of environmental policies and/or the tax system as a whole (Tax Reform). It is necessary to map the required roles and functions for administering the tax and to determine whether they can be carried out with existing capacities or require new roles to be defined and different capacities. Also it is important to establish clear procedures and ensure coordination of key entities, including clear and meaningful penalties for noncompliance

2.1.3. Hybrid System

This section looks at the benefits of hybrid schemes that include elements of both quantity and price management. It has long been recognised there is no need to restrict policy to a pure price or pure quantity instrument, and that a hybrid of the two can have benefits.

An emissions cap combined with a carbon tax can limit total emissions, and so reduce the risk of crossing cumulative thresholds where damage becomes very high, while ensuring that the price never falls below the current marginal cost of damage. Price collars represent a hybrid approach to carbon pricing. If the carbon price under cap-and-trade moves too low or too high, then the price floor or safety valve kicks in and the instrument effectively transforms into a tax (ALDY, 2017).

It is thus likely to form a better approximation to the cost of damages than either a tax or a cap-and-trade alone, better conforming to the basic principle that carbon prices should approximate to the costs of damages (GRUBB, 2012). It also allows the cap to be consistent with a (global) social choice about the acceptable level of risk, while continuing to price emissions below that threshold, so as to stimulate investment to abate emissions that, even if the worst of the risks are avoided, impose costly damage. And it gives a clear signal about the scale of the challenge and the transformational change necessary to meet it.

Therefore, it shall be pointed out that the possibility of using hybrid systems in which price controls are adopted within a market system in order to reduce the volatility of the negotiated values has become more feasible as the international experience has shown. An example is given by the creation of minimum and maximum price references (lower limit and upper limit for prices practiced in the market, as those adopted in California, in Quebec and in the Regional Grennhouse Gas Initiative - RGGI). Another possibility, adopted in the EU ETS, would be to maintain a licenses reserve that would be sold and purchased in order to ensure price stability (Market Stability Reserve) (CEBDS, 2016).

The advantages of a tax may be better accomplished by a hybrid scheme than by a pure tax for simple pragmatic reasons. Emissions trading schemes are already in place in many jurisdictions and it is likely to be easier to move to a hybrid scheme that at least gains some of the benefits of a tax than abolishing an ETS and replacing it completely with a tax. Indeed many ETSs already have elements of price management.

Taxation instruments may also be adopted together with market systems to cover sectors, which would initially be excluded from the regulation. This configuration and combination of instruments have strongly been influenced by political economy factors in which the participation and the power of influence of the regulated agents and of the regulators end up determining choices dictated not only by technical questions

2.1.4. Which CPI and Why?

Although there is broad agreement among economists about the potential advantages of pricing GHG emissions, there is an intense debate as to which would be the best CPI: ETS or carbon tax. From a theoretical point of view, such instruments are equivalent. Therefore, if the regulator has perfect information, the result will be the same, both in terms of the amount of GHG emissions reduced and the abatement cost for both instruments. Thus, if the regulator were able to determine the equilibrium price or the optimal amount of emissions allowed, both options would lead to the social optimum (WEITZMAN, 1974; BAUMOL and OATES, 1988; GOULDER and SCHEIN, 2013). In a perfectly competitive market the use of a carbon tax would be tantamount to establishing an ETS, since it is considered that there is a duality between the two alternatives.

It should be noted, however, that this equivalence is accepted in the case of an ETS in which licenses are sold, not granted free of charge (GOULDER and SCHEIN, 2013). It is known, however, that in practice this theoretical result is unrealistic, since there are other political and economic variables that impact the functioning dynamics of the CPI. Besides, perfect information of regulators and the absence of moral risk and adverse selection are also an ideal situation.

Researchers and academics offer different perspectives on which instrument is better. For example, some argue that a carbon tax is more efficient than an ETS, by stating that such a policy can act directly on issues related to equity and distribution, through different forms of recycling revenues (SHU et al., 2017; POLLITT, 2015; IES-BRASIL, 2015; CHEN, TIMILSINA and LANDIS, 2013; WILLS, 2013; GROTTERA, 2013). In addition, all economic agents know the tax value that does not change quite frequently as in the ETS, offering more security and stability (CHEN, ZHOU and LI, 2017;

MAGALHAES, DOMINGUES and HEWINGS, 2015; INSTITUTO ESCOLHAS, 2015; WILLS and LEFEVRE, 2012; METCALF, 2007).

Others, however, believe that an ETS is a more interesting instrument to reduce emissions, since it is more cost effective and dynamically efficient (ICAP, 2018; YANG et al., 2017; YE et al., 2016; PERTHUS & TROTIGNON, 2015; SANTOS, 2014; RATHMANN, 2012; GURGEL et al., 2011; RATHMANN et al., 2010; KEOHANE, 2009). Yet some argue that an ETS provides opportunity for non-polluters, encouraging efficiency gains (CHOI and LEE, 2016; WORLD BANK GROUP, 2016; LAING et al. 2014; CASTRO and SEROA DA MOTTA, 2013; SEROA DA MOTTA, 2011; LISE; SIJM and HOBBS, 2010; PALTSEV et al., 2008; STAVINS, 2007).

The results of GOULDER and SCHEIN (2013) indicate that, if projected correctly, the two instruments have an equivalent potential. A similar result was found by WEISBACK (2009). The performance of the two instruments critically depends on the specificities of their design. In fact, the conception (design) of the instrument can be as important as the choice between the two instruments.

The key to be analyzed in terms of instrument design is that they set the price differently (WORLD BANK GROUP, 2016; FANKHAUSER, 2010). Under a carbon tax, the price of carbon (or CO_2 emissions) is defined directly by the regulatory authority. On the other hand, in an ETS, the amount of emissions is defined, rather than price. That is, the price of emissions is set indirectly: the regulatory authority determines the total allowed amount of emissions and then the price is established by the supply and demand of licenses in this market (GOULDER and SCHEIN, 2013). Figure 6 represents the functioning of both CPIs.

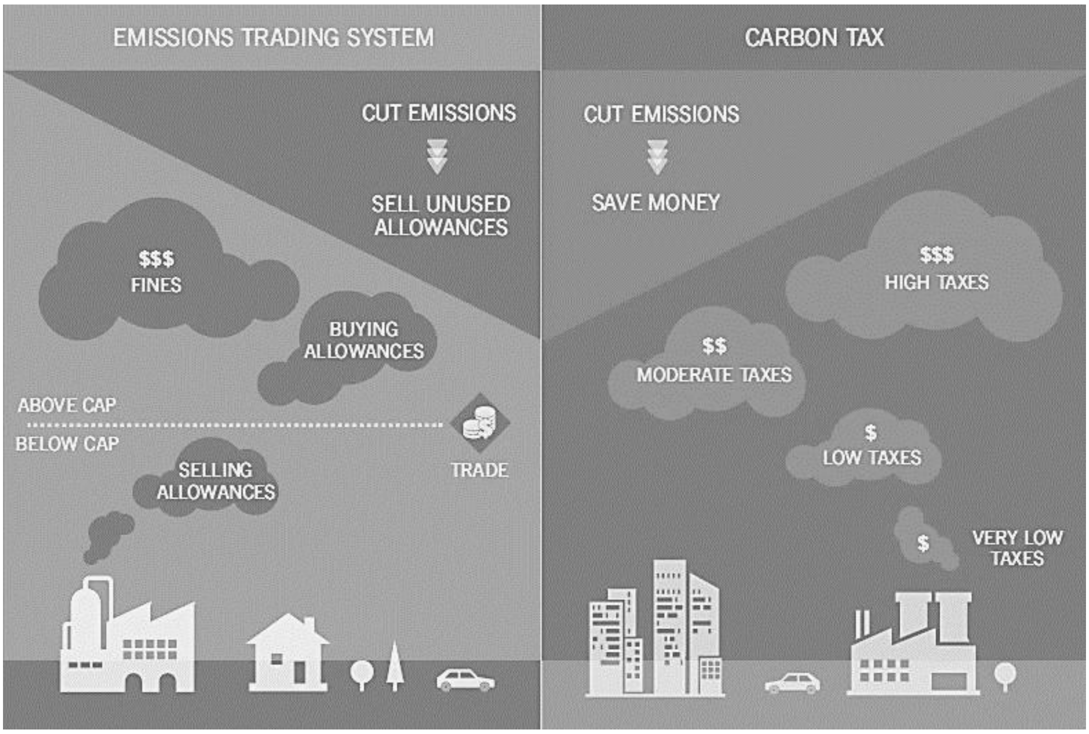


Figure 6 – Functioning of an ETS and a carbon tax

Source: Adapted from CEBDS (2016)

2.2. A Brief Description and Analysis of the Main International Experiences

The following sections describe some carbon pricing experiences and comparatively analyzes them. Such experiences were selected to cover the most relevant ETS and carbon tax implementations in the industrial sector at the supranational, national, and subnational levels. In addition, they represent diverse geographies and span across time, allowing the identification of best practices, linkage opportunities, and learning and knowledge spillovers from older to newer implementations.

2.3.1. ETS Main Experiences

With regard to the ETS main experiences, the following cases will be briefly analyzed: European Union Emissions Trading Scheme (EU ETS), California Cap-and-Trade, New Zealand ETS (NZ ETS), and China ETS. After that, a comparative analysis between these experiences will be carried out with focus on aspects related to the design of the instrument, such as allowance allocation, price control, carbon leakage analysis, and international linking alternatives.

2.3.1.1. European Union Emission Trading Scheme (EU ETS)

The European Union Emission Trading Scheme (EU ETS) was one of the main policy tools used by the EU to implement the Kyoto Protocol. The program begun in 2005 and now operates in 28 EU member states, plus Iceland, Liechtenstein, and Norway. The EU ETS covers about 11,000 entities accounting for 45% of EU-wide GHG emissions (1,988 million metric tons of carbon dioxide equivalent – MMT CO_2e) from multiple sectors, like industry, power and domestic aviation. The EU ETS has proceeded through three distinct trading periods, with phase three (2013–2020)[4] employing an allowance cap reduction of 1.74% per year, a market stability reserve (MSR)[5] to begin in 2019, banking and borrowing restricted to a year, offsets capped at 50% of total emissions reductions, a noncompliance penalty of €100 per ton of regulated emissions, and 50% of auction revenue directed towards climate and energy-related investments (EUROPEAN COMMISSION, 2016; EUROPEAN COMMISSION, 2017; FRUNZA, 2013; MEADOWS, 2017). In this phase, sectors covered are energy intensive industries (EII), including power stations and other combustion plants with > 20MW thermal rated input, oil refineries, coke ovens, iron and steel, cement clinker, glass, lime, bricks, ceramics, pulp, paper and board, aluminum, petrochemicals, ammonia, nitric, adipic, glyoxal and glyoxylic acid production, CO_2 capture, transport in pipelines and geological storage of CO_2 (EUROPEAN COMISSION, 2017).

Declining allowance cap rates every year and a MSR to manage liquidity are two good features that emerged out of EU ETS' experiences with over-allocations during phases 1 and 2. EU ETS is also notable for its decision to progressively increase the auctioning of allowances, with auctioning generating about €14 billion between 2012 and 2016 (double

[4] The legislative framework of the EU ETS for its next trading period (phase 4) was revised in early 2018 to enable it to achieve the EU's 2030 emission reduction targets in line with the 2030 climate and energy policy framework and as part of the EU's contribution to the 2015 Paris Agreement. The revision focuses on: strengthening the EU ETS as an investment driver by increasing the pace of annual reductions in allowances to 2.2% as of 2021 and reinforcing the Market Stability Reserve; continuing the free allocation of allowances as a safeguard for the international competitiveness of industrial sectors at risk of carbon leakage, while ensuring that the rules for determining free allocation are focused and reflect technological progress; and helping industry and the power sector to meet the innovation and investment challenges of the low-carbon transition via several low-carbon funding mechanisms.

[5] MSR is a mechanism established by the EU in 2015 to reduce the surplus of emission allowances in the carbon market and to improve the EU ETS's resilience to future shocks.

dividend). More than 50% of the revenue has been distributed for climate and energy related purposes (EUROPEAN COMMISSION, 2017).

The persistent low price of allowances in spite of market intervention measures is a major concern for the EU ETS system. Over-allocation is reflected in the amount of total emissions reductions achieved since its inception. According to the European Commission, emissions have decreased by about 4.5% between 2011 and 2015 (EUROPEAN COMMISSION, 2017). Many studies estimate a 2.5 to 5% total emissions reduction (about 150-300 MMT CO_2e) during phase 1 and a 6.3% (i.e., 260 MMT CO_2e) from 2008–2009 in phase 2 (BROWN, HANAFI and PETSONK, 2012; HU et al., 2015). The biggest share of abatement, however, is attributable to the 2008 economic crisis rather than the EU ETS (BEL and JOSEPH, 2015). With new measures to reduce the allowance surplus in phase 3, the ETS is anticipated to induce greater emission reductions after 2025 (HU et al., 2015).

2.3.1.2. California Cap-and-Trade

The California Cap-and-Trade program began in 2013 after it was granted legal authority through the Global Warming Solutions Act of 2006 (AB 32), requiring the state to reduce emissions to 1990 levels by 2020. During the first compliance phase (2013–2014), the program covered 35% of the state's emissions (with an upstream coverage of industry, power, transport and buildings), several GHGs (CO_2, CH_4, N_2O, SF_6, HFCs, PFCs, and NF_3). In the second compliance period (2015–2017), the program regulates 85% of California's emissions with free allowances for electric utilities and industrial facilities and 10% auctioned or fixed-price allowances for sectors such as transport, with auctioned allowance revenues allocated for projects related to climate change (C2ES, 2011). In addition, the program contains a $10 price floor with 5% escalator per year and allows offsets up to 8% of a firm's emissions. Especially regarding the industrial sectors, large industrial facilities are covered, including cement, glass, hydrogen, iron and steel, lead, lime manufacturing, nitric acid, petroleum and natural gas systems, petroleum refining, pulp and paper manufacturing, including cogeneration facilities co-owned/operated at any of these facilities (ICAP, 2018).

California Cap-and-Trade program is known for its well-designed ETS containing an allowance price-containment reserve, which gives regulators the power to remove or add allowances into the market, international linkage to the Québec Cap-and-Trade program, free allowances to energy-intensive and trade exposed (EITE) industries to reduce leakage, and rigorous monitoring of allowances, offsets, and emissions reductions (C2ES 2011). The results of the California Cap-and-Trade experience indicate that covered entities steadily reduced emissions, with total emissions attributable to the cap-and-trade program being 9% below the 2014 cap of 160 MMT CO_2e. The California Air Resources Board (CARB) also estimates that California is on track to reach 1990 emission levels by 2020 (CAMUZEAUX, 2015).

This program, however, has faced legal challenges and issues with carbon leakage due to resource reshuffling[6] by electric utilities, which has threatened the integrity of the program (CULLENWARD, 2014). California's complimentary emissions reduction policies such as vehicle emissions standards, renewable portfolio standards, energy efficiency programs, and non-carbon GHG emissions reduction programs are also seen as undermining the proper functioning of the program. This creates potential market uncertainty as regulated entities may not know if the state will meet it complimentary policy goals and obligations in the future, and what effect that will have on allowance prices (DIAMANT, 2013).

2.3.1.3. New Zealand ETS (NZ ETS)

In 2008, the New Zealand ETS (NZ ETS) was introduced by legislation in order to meet the country's international obligations under the Kyoto Protocol, with the objective of delivering emissions reduction in a cost-effective manner while increasing the long-term resilience of New Zealand's economy (RICHTER and CHAMBERS, 2014). Until 2015, the ETS covered all sectors under a Kyoto-based target without a nationwide emissions cap. From 2016, the ETS imposes a nationwide emissions-intensity-based cap, upstream regulation in the energy sectors, voluntary opt-in for downstream users, output-based grandfathering of allowances to eligible EITE sectors, such as agriculture, with a linear phase-out of free allowances by 2030, unlimited Kyoto offsets until 2015, and a strict

[6] CARB defined resource shuffling as "any plan, scheme, or artifice to receive credit based on emissions reductions that have not occurred, involving the delivery of electricity to the California grid" (CARB, 2010).

MRV process with audits of self-assessment and penalties for non-compliance (ICAP 2017; LEINING and KERR, 2016).

The NZ ETS specifies the activities that are included for each of the following sectors: forestry, liquid fossil fuels, stationary energy, industrial processes, synthetic greenhouse gases, agriculture and waste. In the industrial processes sector, certain businesses have obligations to report their activities and surrender New Zealand Units (NZUs) under the scheme. They are: iron and steel, aluminum (including carbon dioxide and perfluorocarbons (PFCs) emissions), clinker or burnt lime (resulting in calcination of limestone or calcium carbonates), glass (using soda ash), and gold (if the CO_2-equivalent emissions per annum exceed 5000 tons) (EPA, 2018).

NZ ETS is known for its unique “no cap” approach to reducing emissions in order to achieve its Kyoto obligations. The scheme allowed for unlimited purchase of international offsets and issued free domestic NZU to its participants in order to garner political support for the program. The program indicates that it is learning from its prior policy failings, as the ETS starting in 2016 imposes a domestic emissions cap, phases out free allowances by 2030, and restricts the trading of international offsets. However, although NZ ETS met its Kyoto obligations during the first commitment period and is expected to do so during the second one as well (MINISTRY FOR THE ENVIRONMENT, 2016a,b), the experiment of running an ETS market with full international linkage without a domestic emissions cap has not resulted in significant domestic emissions reductions. BERTRAM and TERRY (2010) conclude that domestic emissions were reduced only by 23 MMT CO_2e in 2008 and only by 19 MMT CO_2e in 2009. BULLOCK (2012) argued that the integrity of the ETS has been undermined by interest groups, particularly from the agriculture sector, thereby delaying significant technological upgrades and emissions reduction in the country. Free allowances to EITE firms, the absence of a nationwide emissions cap, and an international offset cap until 2015 allowed many ETS participants to meet their obligations without significantly reducing firm level emissions.

2.3.1.4. China ETS

In 2011, the Chinese government initiated seven pilot ETS programs for CO_2 emissions (Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Guangdong, and Hubei) requiring the regions to launch them by 2013 and fully initiate by 2015 (ZHANG et al., 2014). Chinese

ETS pilots covered indirect electricity emissions within the pilot regions and emissions from imported electricity outside of the pilot regions (ZHANG, 2015). Nearly all of them allocated allowances for free, except for a small percentage of auctioning in Guangdong, Shenzhen, and Hubei, but the systems differed in their method of allocation (DONG, MA and SUN, 2016; DUAN, PANG and ZHANG, 2014). All of them accepted offsets through Certified Emission Reductions (CERs) generated outside the pilot regions and established market stabilizing mechanisms using auctions triggered by price ceilings, allowance reserves, buy-back of surplus allowances in the market, or a combination of these features (PANG and DUAN, 2016).

Incomplete reporting practices, a lack of a legal framework to enforce compliance, and weak penalties are identified as some of the key challenges that emerged in the seven pilots (YU and LO, 2015). A survey of Chinese firms conducted in 2015 revealed that the carbon price failed to "stimulate companies to upgrade mitigation technologies" and that the majority of firms considered participation in the ETS pilots only a means of improving ties with governments and earning a good social reputation (YANG, LI and ZHANG, 2016).

However, on the 19th of December 2017, China's National Development and Reform Commission (NDRC) announced the official launch of the anticipated national ETS. In a historical achievement, China recently launched the world's largest carbon market that will cover eight key emitting sectors, starting with the power sector, then including the chemical, petrochemical, iron and steel, non-ferrous metal, building materials, paper making, and aviation sectors (ICAP, 2018). Enterprises in these sectors that exceed the annual threshold of 26,000 metric tonnes of CO_2 emissions (energy consumption of more than 10,000 tce) are already requested by the government to report and verify their historical CO_2 emissions, with the aim to collect and improve data quality (ICAP, 2018). This data will then support the development and implementation of sound allocation plans.

2.3.1.5. Comparative Analysis

In terms of *emissions cap*, EU ETS initially employed a bottom-up approach to deciding emission targets in their first compliance periods, with the EU allowing its member states to determine their respective national emission caps based on historical emissions benchmarks (HU et al., 2015). However, after facing a substantial over-allocation of 220 million allowances and a resulting complete price collapse, the EU ETS decided to aggregate all member state emissions caps into a single EU-wide emissions cap that decreases at 1.74% a year (MEADOWS, 2017; SCHUMALENSEE and STAVINS, 2015). California set top-down emissions caps based on projected emission levels calculated using estimates of future economic growth. In NZ ETS, the intensity-based nationwide cap from 2016 may lead to varying abatement costs each year as its economy is primarily driven by weather-dependent primary production (47% of GDP from agriculture). Finally, the Chinese ETS pilots vary significantly in the way they set their emissions targets with Guangdong choosing an absolute cap, Shanghai allocating allowances without announcing an emissions cap, and Shenzhen issuing both intensity and absolute caps for the 2013–2015 period. Reflecting the variation in economic conditions between the Chinese cities, between 2013 and 2015, Guangdong increased its emissions cap to allow for increased industrial production, Hubei decreased its cap to reflect new economic growth patterns, Chongqing reduced its cap by 4.13% a year, and Beijing, Shanghai, Tianjin, and Shenzhen kept their caps unchanged (XIONG et al., 2017).

Once the emissions cap is decided, policymakers must define the *allowance allocation and distributional method*. The EU ETS was initiated with a politically-palatable, free, grandfathered allowance-allocation method, based on a bottom-up reporting of historical emissions by firms in each member state in its first compliance period. Over time, the EU ETS has transitioned to a benchmarking system that calculates allowances based on a product's benchmarked emissions and historical production (EUROPEAN COMISSION, 2011). Similarly, California initially allocated allowances for free and calculated its allocations based on a benchmarked, three-year moving-average output for each industry (CARB, 2010). In the second trading period (2013–2020), California uses a mix of free allocations, auctioning, and fixed price allowance sales for different sectors (C2ES, 2011). The NZ ETS gave preferential treatment to its EITE sectors (i.e., agriculture and land use sectors) by assigning free allowances based on grandfathered historical emissions, fixed until 2018, with a linear phase-out of free allowances starting in 2019 and moving to full auctioning by 2030 (BULLOCK, 2012). Recently, the New Zealand government decided to phase out its one-for-two transitional measure by 2019 in order to meet its climate change targets and incentivize firm level emissions reductions (MINISTRY OF THE ENVIRONMENT, 2016b). Finally, the Chinese ETS pilots chose to allocate based on the method that best suited the region's economic structure. Beijing and Tianjin pilots used a combination of historical emissions, historical carbon intensity, and industrial benchmarks to allocate based on the region's historical average carbon intensity multiplied by an intensity decline coefficient (XIONG et al., 2017). Shanghai uses early action incentives to encourage early movers and employs a rolling baseline year so that enterprises can use the latest year's emissions data as a benchmark to receive allowances if their emissions increased over 50% from 2009 to 2011 (XIONG et al., 2017). Guangdong and Hubei pilots follow the Shanghai formula without issuing early-action incentives, while Chongqing relies on self-declaration of emission reductions by entities. Shenzhen allocates 90% of allowances for free based on industrial benchmarks. For the manufacturing sector, Shenzhen follows a novel approach of post-allocation adjustment based on the difference between expected and actual firm-level emissions. Manufacturing firms are required to follow a strict MRV process and report their emissions output every year for adjustment (YE et al., 2015). Out of the seven pilots, Beijing, Shenzhen, and Hubei follow California's hybrid approach of distributing allowances freely, through auction, and by fixed price sale. Shanghai, Tianjin, and Chongqing pilots distribute entirely for free, while Guangdong uses a combination of free distribution and auction (XIONG et al., 2017).

Considering the *price control mechanisms*, the EU ETS in phases 1 and 2, California in phase 1, and New Zealand witnessed excess allowances resulting from over-allocation. The EU experienced over-allocation of up to 900 million allowances and a complete price collapse in its first compliance period due to grandfathered permits based on member state reported emissions. Subsequent over-allocation in the second compliance period was due to the economic downturn, even in spite of a 6.5% reduction in allowances and auctioning of 10% of allowances (EUROPEAN COMISSION, 2016). In the third compliance period, EU ETS created the MSR to begin operating in 2019, with the aim of aligning the demand and supply of allowances by placing surpluses into the MSR and releasing them in the event of an allowance shortage (EUROPEAN COMISSION, 2017; HU et al., 2015). California witnessed excess market liquidity and price volatility in their initial compliance periods primarily due to miscalculation of future growth projections and thereby set the emissions cap too high. As a result, California established a price floor and created an allowance price containment reserve similar to the EU, which regulators can use to increase or decrease allowance liquidity in the market. Since NZ ETS came under an overall Kyoto emissions cap in its first compliance period, the glut of Kyoto offsets led to a collapse in the allowance price from $20 in May 2011 to $2 in May 2013 (RICHTER and CHAMBERS, 2014). Unlike the California system, until 2015, the NZ ETS did not have a cap- or a price-based circuit breaker on the number of international offset credits that could be purchased by participants. In its second compliance period, NZ ETS responded by bringing the program under a nationwide emissions cap and closing access to international Kyoto offset credits (DIAZ-RAINEY and TULLOCH, 2015).

Carbon leakage always appears as a major concern in ETS initiatives[7]. In California, leakage has occurred as regulated entities, primarily utilities, shuffle their resources through out of state electricity purchases. California imports large amounts of electricity, roughly 33.5% in 2015 (much of it either coal or natural gas based), from other western states that do not have carbon pricing mechanisms (CEC, 2017). This practice allows regulated California utilities to switch from "dirtier" to "cleaner" electricity resources by rearranging ownership or contracts with out-of-state generators, and then claim the difference in emissions as reductions in firm-level emissions. Estimates of the potential leakage range from 120 to 360 MMT CO_2e in total measured emission reduction under the cap-and-trade program, a significant amount in light California's goal to reach 1990 emission levels (approx. 431 MMT CO_2e) by 2020 (BORENSTEIN et al., 2014; CARB, 2017). In the case of New Zealand, carbon leakage appeared in the form of Kyoto offsets and HFC-23-related credits from other markets that were easily brought into the NZ ETS market, thereby undermining the creditability and environmental effectiveness of the program (DIAZ-RAINEY and TULLOCH, 2015). Although the new intensity-based allocation in NZ ETS may stem domestic carbon leakage, it could encourage increased international leakage, with emitters from other countries with stricter emission requirements relocating to New Zealand (BERTRAM and TERRY, 2010).

When looking at the *international linking* possibility, California is notable for its international linkage with the Québec cap-and-trade program beginning in 2014. The two systems were fairly easy to link due to extensive and transparent communications

[7] Section 4.2.1. will describe in detail the main methodologies developed for assessing the carbon leakage risk used by international experiences.

between the two governments going as far back as 2008 (BENOIT and CÔTÉ, 2015). California and Québec created a common electronic allowance registry to avoid gaming and potential double-counting. Strong verification and data accuracy safeguards were put in place to ensure the integrity of allowance credits, in addition to that of the offsets. To maintain price stability, the price floor was set at the highest minimum price of either region, in USD. Linking with the California system allowed Québec's cap-and-trade market to increase its liquidity through increased access to allowances, with analysis indicating that Québec could potentially purchase between 14.4 and 18.3 million allowances from California, based on projected demand for allowances (CARB, 2012). Nevertheless, on the delinking side, DIAZ-RAINEY and TULLOCH (2015) argue that NZ ETS shows both the power and dangers of tacit linking to international carbon markets. Due to excess liquidity from international offsets, the NZ ETS had to delink itself from CDM and offset markets in 2015 and move towards a domestic market (BULLOCK, 2012). The EU ETS also delinked from the international CDM market in 2012. In China, the idea is to link all the pilot programs into a national China ETS.

Considering the *carbon revenue management*, the EU ETS generated about €14 billion in auctions between 2012 and 2016, with at least 50% of the revenue distributed for climate and energy-related purposes and retrofitting existing infrastructure (EUROPEAN COMISSION, 2017). The EU plans to establish two new funds: an Innovation fund to extend existing support for demonstration of innovative technologies, and a Modernization fund to facilitate investments in modernizing the power sector and fostering energy efficiency (MEADOWS, 2017). California raised $3.385 billion in revenue through 2017 and has invested revenue into high-speed rail, low carbon transit, low-income weatherization, and environmental conservation efforts (CCI, 2017).

Table 3 summarizes and compares the main features of the analyzed experiences.

Table 3 – ETS' Features and Comparisons

Source: Own elaboration based on NARASSIMHAN et al. (2018), EUROPEAN COMISSION (2017), ICAP (2018), CARB (2010, 2012), C2ES (2011), MINISTRY FOR THE ENVIROMENT (2016a,b), EDF, MOTU and IETA (2014), ZHANG (2015), XIONG et al. (2017), SWARTZ (2016)

Feature	EU ETS	California Cap-and-Trade	NZ ETS	China ETS
General Information				
Jurisdiction	28 EU-member states, plus Iceland, Liechtenstein, and Norway	California	New Zealand	Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Guangdong, Hubei
Start Date	2005	2012	2011	2013
Compliance Period Duration	1st phase (2005-2007), 2nd phase (2008-2012), 3rd phase (2013-2020), 4th phase (2021-2030)	1st period (2012-2014), 2nd period (2015-2017), 3rd (2018-2020)	Yearly Compliance periods since 2011	Pilot phase (2013-15). National ETS (phase 1: 2018; phase 2:2019; phase 4: 2020-2030)
Regulating Authority	European Commission Directorate General for Climate Action	California Air Resources Board	Ministry of the Environment, Environmental Protection Authority, Ministry of Primary Industries	Development and Reform Commissions of each region
Offsets	The overall use of credits is limited to 50% of the EU wide reductions over the period 2008–2020	Up to 8% of each entity's Compliance obligation	Unlimited (domestic offsets, related to the forestry sector), but international offsets are not eligible	Beijing: -; Tianjin: 10%; Shanghai: 5%; Chongqing: 8%; Shenzhen: 10%; Guangdong: 10%, of which 70% of offsets must be located in Guangdong province; Hubei: 10% for new entrants, 15 for pilot ETS participants
Emissions Cap				
GHGs Covered	CO_2, N_2O, PFCs (individual states may add more GHG emissions)	CO_2, CH_4, N_2O, SF_6, HFC, PFCs, NO_3	CO_2, CH_4, N_2O, SF_6, HFC, PFCs	CO_2
Entities Covered	10,950	450	2,364	Beijing: 490; Tianjin: 197; Shanghai: 191; Chongqing: 230; Shenzhen: 635; Guangdong: 830; Hubei: 107
Overall Emissions Coverage	45%	85%	51%	Beijing: 50%; Tianjin: 45%; Shanghai: 60%; Chongqing: 40%; Shenzhen: 40%; Guangdong: 60%; Hubei: 33%
Sectorial Coverage	Power plants over 20MW thermal rated input, energy intensive industry, oil refineries, coke ovens, iron and steel, cement clinker, glass, lime, bricks, ceramics, pulp and paper board, aluminum, petrochemicals,	Large industrial facilities (including cement production, glass production, hydrogen production, iron and steel production, lead production, lime manufacturing, nitric acid production, petroleum and natural gas systems, petroleum refining, pulp and paper manufacturing, including cogeneration facilities	Sectors gradually phased-in, forestry (2008), stationary energy, industrial processing, liquid fossil fuels (2010), waste and synthetic GHGs (2013)	Beijing: 17 manufacturing industries, commercial buildings, public utilities. Greater than 10,000 metric tonnes/CO_2 per year. Heat and electricity production, iron, steel, nonferrous metal, petrochemicals, pulp and paper, glass, cement; Tianjin: Oil and gas exploration, buildings; Greater than 20,000 metric tonnes/CO_2 per year for industry, 10,000 metric tonnes/CO_2 per year

	ammonia, nitric, adipic, glyoxal and glyoxylic acid production, CO_2 capture, transport in pipelines, geological storage of CO_2, flights between EU airports	co-owned/operated at any of these facilities), electricity generation, electricity imports, other stationary combustion, and CO_2 suppliers, suppliers of natural gas, suppliers of reformulated blend stock for oxygenate blending (RBOB) and distillate fuel oil, suppliers of liquid petroleum gas in California and suppliers of liquefied natural gas. Facilities ≥25,000 tCO_2e (metric) per data year		for other sectors. Heat and electricity production, iron, steel, nonferrous metal, petrochemicals, pulp and paper, glass, cement; Shanghai: Textiles, commercial buildings, and airlines. Greater than 20,000 metric tonnes /CO_2 per year. Heat and electricity production, iron, steel, nonferrous metal, petrochemicals, pulp and paper, glass, cement; Chongqing: Greater than 20,000 metric tonnes /CO_2 per year. Heat and electricity production, iron, steel, nonferrous metal, petrochemicals, pulp and paper, glass, cement; Shenzhen: 26 manufacturing industries, commercial buildings and transportation. Greater than 5,000 metric tonnes/CO_2 per year. Heat and electricity production, iron, steel, nonferrous metal, petrochemicals, pulp and paper, glass, cement; Guangdong: Textiles, commercial buildings, and transportation. Greater than 20,000 metric tonnes/CO_2 per year. Heat and electricity production, iron, steel, nonferrous metal, petrochemicals, pulp and paper, glass, cement; Hubei: Automobiles. Greater than approximately 120,000 metric tonnes/CO_2 per year. Heat and electricity production, iron, steel, nonferrous metal, petrochemicals, pulp and paper, glass, cement
Allowance Allocation and Distributional Method				
Allowance Allocation Method	Although in phase 3 auctioning is the default method for allocating emission allowances to companies participating in the EU ETS, some allowances continue to be allocated for free until 2020 and beyond. 41% of the total quantity of allowances will be allocated for free over phase 3	Allowance allocation method is mixed between auction and free allocation. Electric utilities, industrial facilities, and natural gas distributors, allowances allocated freely, with a declining total over time. Other covered sectors, such as transportation, natural gas extraction, and other fuel sources, allowances must be purchased at auction or through the allowance trading platform	Mixed, 90% free allocation for high EITE entities, 60% free allocation for moderately EITE. In 2016, industries – 4.6 million allowances, forestry carbon sequestration – 8.5 million allowances	Beijing: Free allocation; Tianjin: Mixed, free allocation (major) auction and fixed price distribution; Shanghai: Mixed, free allocation and auction; Chongqing: Free allocation; Shenzhen: Mixed, free allocation, with no more than 10% auction Guangdong: Mixed, 97% free allocation with 3% auction; Hubei: Mixed, free allocation with 2.4% auction
Price Control Mechanisms				
Current Allowance Price per ton of CO_2e (Nominal $, 2017	$6.8 (August 2017)	$13.80 (May 2017)	$12.54 (June 2016)	Beijing: $8.14 (June 2016); Tianjin: $2.88 (June 2016); Shanghai: $1.08 (June 2016); Chongqing: $1.52 (June 2016); Shenzhen: $5.46 (June 2016); Guangdong: $2.00 (June 2016); Hubei: $2.49 (June 2016)

Exchange Rates)				
Banking and Borrowing	Banking is allowed since phase 2. Borrowing is restricted to within one-year	Banking is allowed but the emitter is subject to a general holding limit. Borrowing of future vintage allowances is not allowed	Banking allowed of allowance credits, except for those purchased under the fixed price option. Borrowing is not allowed	No borrowing. Banking is allowed during pilot phase
Price Collar (Floor/ Ceiling)	Market Stability Reserve will begin operation in 2019, aiming at stabilizing market and price of allowances. Allowances added to reserve is total circulation higher than 833 million allowances	Auction Reserve Price: $13.57. The auction reserve price increases annually by 5% plus inflation, as measured by the Consumer Price Index. Price ceiling for allowances tiered at $50.69, $57.04, and $63.37. Tier prices increase by 5% per year, plus inflation	Fixed price ceiling of $18.67% allowance surrender obligation from 2017, increases to 83 in 2018, and full surrender obligation in 2019	Regulating authority can auction extra allowances if average weighted price exceeds $22.75 and buy back allowances if price falls to $3. Guangdong: price floor set at roughly $1.5
		Carbon Leakage		
EITE Protection	Manufacturing sub-sectors deemed at high risk for carbon leakage receive 100% free allocation. Sectors not deemed to be at risk of leakage will draw down free allowance allocation from 80% in 2013 to 30% by 2020	Receive free allowances for transition assistance and to prevent leakage. Starting in 2018, transition assistance declines. The amount of free allocation is determined by leakage risk (measured through emissions intensity and trade exposure) and sector-specific benchmarks	90% free allocation for high EITE entities, 60% free allocation for moderately EITE	Free allowance allocation in some subnational jurisdictions
		International Linking		
Alternatives of International Linking	Soon to be linked with Swiss ETS	Linked with Québec ETS in 2014 and Ontario cap-and-trade (2017)	No international linkage	No international linkage
		Carbon Revenue Management		
Revenue Generated (2017 Exchange Rates)	$16.45 billion (2012–16)	$3.4 billion (2012–16)	n/a	n/a
Revenue Allocation	At least 50% of auction revenues must be distributed for climate and energy related purposes.	25% to high-speed rail projects, 20% to affordable housing an sustainable communities program, 10% to intercity rail program, 5% to low carbon transit options, at least 25% of proceeds must be invested in projects that are located within and benefiting disadvantaged communities, at least 5% benefiting low-income communities, at least 5% benefiting disadvantaged communities	Compensation for the effect of the ETS on asset values in the fishing and forestry sectors, and prevention of ETS-driven loss of competitiveness and carbon leakage in the industrial sectors. Allocation in the industrial sectors is intensity-based	Mitigation of EITE's competitiveness impacts

n/a: not available

2.3.2. Carbon Tax Main Experiences

This section briefly describes the carbon tax systems of Australia, British Columbia, Norway, and Mexico, besides comparting and contrasting the design and implementation features, constraints, and other issues faced by these systems. Cases were selected to cover carbon tax policies that varied in their sectorial coverage (mainly focusing on the industrial sector), taxation on carbon content of the fuel instead of direct carbon emissions, taxation on one particular source of fuel, revenue redistribution, and the presence of a hybrid with cap-and-trade systems.

2.3.2.1. Norway's Carbon Tax

Following the publication of the Brundtland report, Our Common Future, in 1987, the Norwegian government introduced an upstream carbon tax on oil and gas extractors, hydrofluorocarbons/perfluorocarbons (HFC/PFC) importers and a downstream tax on oil and gas suppliers. The tax system allows some sectors such as pulp and paper, fishmeal, domestic aviation, and shipping to pay reduced rates and other sectors covered by the EU ETS and external aviation to be exempt from the carbon tax. Although EU ETS sectors are exempt from the carbon tax, there seems to be significant overlap between the carbon tax and EU ETS covering the same base emissions in sectors such as electricity (58%), industry sector (54%), and off-road transport sector (30%) (OECD, 2015).

Norway's carbon tax is notable for its ambitious tax rate between \$3 and \$64 per ton of CO_2e in different sectors since its introduction in 1991. Norway also taxes non-CO_2 GHG emissions from NO_x, SO_2, and HFC/PFC. The government has maintained policy stability and clear price signals for private sector companies willing to invest in clean energy technologies. Since 2013, about 30% of carbon tax revenue is being earmarked into a special fund for climate, renewable energy and energy efficiency measures.

In order for Norway to meet the EU target of 30% emissions reduction in non-EU ETS sectors by 2030, the tax rate needs to be significantly higher on motor fuels (BYE and BRUVOLL, 2015). The Green Tax Commission has recommended a single tax rate of \$49 per ton CO_2e for all non-EU ETS sectors (WORLD BANK et al., 2018). Stiff political resistance to higher carbon tax rates has made policy changes unlikely in the near future (PMR, 2017). In terms of emissions reduction since 1991, the Ministry of Climate and

Environment estimated in 2014 that the country's total emissions would have been 6-7 million metric tonnes of CO_2e higher than they were without the tax in place (PMR 2017). Between 1991 and 2008, total CO_2 emissions in Norway only increased by 15% while the GDP grew 70% during the same period (SUMNER et al., 2011). However, during that period, CO_2 emissions from petroleum and natural gas extraction increased 86%, while general emission growth was only 6%. With inelastic European demand for oil and gas extraction, which is taxed, exemptions for shipping exported oil and gas sold through pipelines, and a domestic energy mix already dominated by hydropower and renewables, the carbon tax does not seem to have created any significant domestic reduction of total emissions (LIN and LI, 2011).

2.3.2.2. British Columbia's Carbon Tax

British Columbia (BC) has the longest running carbon tax policy in Canada. The economy-wide tax rate is \$30/ton of CO_2e, covering more than 70% of the region's GHG emissions with sectorial exemptions for the remaining 30% of GHG emitting sources (MURRAY and RIVERS, 2015).

A defining feature of the BC carbon tax is its revenue neutrality. This design decision won support from the business community as BC redistributed the revenues to reduce industrial property taxes and other corporate taxes for industries affected by the tax. Overall, data indicate that BC's carbon tax has reduced emissions with few negative effects on the economy (MURRAY and RIVERS, 2015; METCALF, 2015). An analysis of several different models shows that the carbon tax reduced emissions between 5%-15%, in absence of any additional policy when compared to a business-as-usual scenario (MURRAY and RIVERS, 2015). The province decreased per capita emissions by 12.9% by 2013 when compared to pre-carbon tax levels, more than three-and-a-half times the 3.7% per capita decline nationwide (METCALF, 2015). As of 2015, BC has reduced 2.8 million metric tonnes of GHG when compared to the pre-tax period, with a GDP growth of 1.55% (higher than the national average of 1.44%) between 2008 and 2013 (KOMANOFF and GORDON, 2015).

The defining feature of revenue neutrality is by itself a constraint for BC's carbon tax system. The system does not have any plans to transition from revenue neutrality to earmarking of funds for reinvesting in emissions-reducing activities. In addition, sectorial exemptions and carbon tax politics can undermine popular support for the policy.

2.3.2.3. Australian Carbon Pricing Mechanism (CPM)

The Australian government introduced a carbon pricing scheme or "carbon tax" through the Clean Energy Act 2011. The Australian CPM was intended to control emissions in the country, as well as support the growth of the economy through the development of clean energy technologies (BAILEY et al., 2012). It was supervised by the Climate Change Authority and the Clean Energy Regulator. However, although it did achieve a reduction in the country's carbon emissions, the initiative faced significant challenges from the opposition and the public, as it resulted in increased energy prices for both households and industry and was finally repealed in 2014.

Each year, selected entities were required to surrender one emission unit for every tonne of carbon dioxide equivalent (CO_2e) they produced. In the first year (2012–13), carbon units could be purchased from the Clean Energy Regulator for a fixed price of AUD23 per unit, and in 2013-14, carbon units could be purchased for AUD24.15 per unit (FREEBAIRN, 2012). Those who did not surrender any or enough units incurred a "unit shortfall charge". This charge created an incentive for companies to surrender extra units under the mechanism rather than pay a higher unit shortfall charge (CER, 2015).

Following the closure of the Australian CPM, the Emissions Reduction Fund (ERF) has formed the primary market for Australian Carbon Credit Units (ACCUs), with the Clean Energy Regulator entering into contracts to purchase offsets from developers active in the land-use and industrial sectors. The ERF operates as a competitive reverse auction mechanism, with confidential bids submitted to the Clean Energy Regulator, and accepted subject to clearing rules, which can vary by auction. The Clean Energy Regulator sets a benchmark price for each auction, or price ceiling, which is not disclosed to the market. Eligible bids are placed in a bid stack and ranked by price offered, with bids above the benchmark price excluded from consideration. All bids up to 25 per cent of the volume offered under the benchmark price are accepted, with the Regulator selecting bids above this point based on perceived value. Following each auction, the Clean Energy Regulator discloses the volume weighted average price of ACCUs contracted, with individual contract prices not released (CER, 2015). While the true price for ACCUs is made up of a wide spread in contract prices, the volume-weighted price is influenced by the size of projects contracted at different price points.

2.3.2.4. Mexico Carbon Tax

In 2013, as part of a broader fiscal reform effort, Mexico became the first Latin American country to establish a carbon tax with widespread support of the domestic think tanks and Non-Governmental Organizations (NGOs) (MUÑOZ, 2015). Mexico's carbon tax builds on the national climate change law approved by the Mexican Congress in 2012, with the goal of reducing GHG emissions by 30% by 2020 and 50% by 2050 (CDC et al., 2015). An average tax of $3.21 per ton of CO_2e is levied upstream at the production stage on the carbon content of the fuels (OECD, 2014), with exemptions for natural gas production and import, and an offset mechanism allowing the use of certified emissions reduction (CER) credits by eligible Mexican projects (CDC, EDF, and IETA, 2015; MEXICO IEPS LAW, 2015).

Mexico's tax rate is the lowest among OECD countries (IMF, 2015) and one of the lowest in the world (WORLD BANK et al., 2018). Since natural gas accounts for about 30% of Mexico's energy-related CO_2 emissions and is exempted, the tax only covers about two-thirds of Mexico's fossil fuel-related emissions (METCALF, 2015). Low prices combined with exemptions for natural gas act as major constraints in achieving higher ambition. The annual revenues expected at this rate are about $1.1 billion, representing less than 1% of the total federal tax collections (METCALF, 2015). However, despite low prices and revenue, there is currently no plan to increase the tax rate over time, with the exception of adjusting fuel rates annually for general inflation. The low tax rate is estimated to reduce CO_2e emissions by 1.6 million metric tonnes of CO_2e, representing just 0.33% of Mexico's total emissions per year (METCALF, 2015).

The Mexican carbon tax is operating in parallel to a voluntary carbon exchange market called MexiCO_2 that allows for the exchange of CER offsets with taxes. It became an official ETS, when the Mexican Ministry of Environment and Natural Resources announced the market rules for the ETS and updated rules for the National Emissions Register, starting the operation in two phases in August 2018 (ICAP, 2018). The first phase (pilot phase) will last for three years until August 2021. Subsequently, the rules will be updated for the start of the second phase (formal phase), which will also be in line with the start of the first accounting period under the Paris Agreement in 2021. In this context, Mexico is also actively seeking to link its ETS to markets in North America. To this end, Mexico signed a Memorandum of Understanding (MoU) with Québec and Ontario that includes cooperation on ETS. Additionally, in December 2017, Mexico, together with four countries (Canada, Colombia, Costa Rica and Chile) and seven subnational governments (Governors of California, Washington and the Premiers of Alberta, British Columbia, Nova Scotia, Ontario and Québec), issued the Paris Declaration on Carbon Pricing in the Americas for carbon pricing implementation (ICAP, 2018).

2.3.2.5. Comparative Analysis

In terms of *pricing setting*, British Columbia's carbon tax started with a flat economy-wide \$10 price per ton of CO_2e and a \$5 increase per year until reaching \$30 per ton in 2012 (MURRAY and RIVERS, 2015). The same happened to Australia: in the first year (2012–13), carbon units could be purchased for a fixed price of AUD23 per unit, and in 2013–14, carbon units could be purchased for AUD24.15 per unit (FREEBAIRN, 2012). However, other carbon tax systems do not have a codified annual escalator to reach a desired carbon price. For instance, Mexico taxes fuels differentially ranging from \$0.43 to \$3.44 per ton of CO_2e emissions (METCALF, 2015). Similar to Mexico, Norway imposes a variable tax rate ranging from \$3.5 to \$64 per ton of CO_2e on fossil fuels and greenhouse gases across different sectors, with the exception of a high rate of \$432 per ton of CO_2e for "natural gas emitted to air". In both Australia and Mexico there was the conception to transition from a carbon tax to an ETS, facts that has been occurring recently.

Carbon taxes vary widely in terms of *sectorial coverage*. To ensure economic efficiency, a carbon tax would ideally be economy-wide, covering all emitting sources at either the production (upstream) or consumption (downstream) stage. Looking at the experiences analyzed, the Norwegian carbon tax covers about 60% of its GHG emissions and 80% of the country's emissions along with EU ETS (BRAGADÓTTIR et al., 2015). British Columbia's downstream economy-wide carbon tax covers 70%–75% of all provincial

GHG emissions from facilities that emit more than 10,000 metric tonnes of CO_2e per year, including emissions from liquid fossil fuels, natural gas, coal, and other GHGs such as methane, nitrous oxide, and land-use change emissions (MURRAY and RIVERS 2015). Other countries impose a tax on the fuel or the estimated carbon content of fossil fuels instead of GHG emissions. The carbon tax covered approximately 60% of Australia's carbon emissions including from electricity generation, stationary energy, landfills, wastewater, industrial processes and fugitive emissions. Mexico levies an upstream tax on the sale and import of fossil fuels depending on the relative carbon content of a fuel with respect to natural gas as the baseline (i.e., zero tax for natural gas) (MEXICO IEPS LAW, 2015). The Mexican carbon tax covers about 40% of the country's total GHG emissions. Norway imposes an upstream carbon tax on fuel sources such as oil and gas used for petroleum extraction activities in the continental shelf, HFC/PFC importers, and a midstream tax on oil, natural gas, and LPG fuel suppliers.

Some carbon tax systems address *carbon leakage* by exempting energy-intensive and trade exposed (EITE) enterprises from paying the tax in order to reduce competitiveness impacts. Both Norway and British Columbia exempt the fuels exporting process out of the region and emissions from shipping and air travel. In addition, British Columbia exempts emissions from agricultural production and other non-fossil fuel GHG emissions such as methane leakage from landfills, forestry, agriculture, and natural gas production. EITE sectors such as the cement sector in British Columbia were even able to secure a one-time transition incentive of $22 million to buy in to the carbon tax system, essentially establishing precedent for targeted incentives to improve political acceptability (MURRAY and RIVERS, 2015). The Australian carbon pricing mechanism included systems for assessing liability for emissions, issuing free units to EITE industries, meeting liability for emissions through payment and surrender processes for eligible emissions units, and relinquishing units (CER, 2015). Mexico exempts the entire natural gas production and supply from the carbon tax.

A crucial design consideration for carbon taxation is the *carbon revenue management* aiming at the allocation of revenue generated from the carbon tax. Norway's carbon tax revenues are directed towards the general budget and the country uses the revenue to reduce income and capital taxes, labor taxes, and provide pension plans for low-income citizens. Similar to Norway, British Columbia, with the highest coverage adjusted carbon price of $17 per ton of CO_2e (2016 ppp), redirects almost all of its revenue towards the general budget. The British Columbia carbon tax generated about $7.3 billion in revenue between 2008 and 2015, with revenue allocated towards low-income tax credits, reducing the bottom two personal income tax brackets by 5%, issuing direct cash transfers to Northern and rural residents of the region, reducing corporate and small business tax rates, and industrial property tax credits (KOMANOFF and GORDON, 2015). Revenue generated by the carbon price in Australia was planned to ease costs for households and industry and for investment in renewable power, energy efficiency, and other low-carbon alternatives (C2ES, 2011). Mexico also reinvests its carbon tax revenues towards public spending in different ways. However, the country has not mentioned specific earmarking towards renewable energy investments. In Mexico, the revenue collection agency (SAT, by its Spanish acronym) secures the revenue and directs it to the general funds and does not use it either for green spending or revenue recycling (MUÑOZ PIÑA, 2015; CARL and FEDOR, 2016). Additionally, eligible Mexican projects can offset their carbon tax with CER credits through the MexiCO_2 carbon exchange market.

Table 4 summarizes and compares the main features of the analyzed experiences.

Table 4 – Carbon Taxes' Features and Comparisons

Source: Own elaboration based on PMR (2017), ROYAL NORWEGIAN MINISTRY OF FINANCE (1990), BRITISH COLUMBIA LAW (2008), WALTERS and MARTIN (2012), MEXICO IEPS LAW (2015).

Feature	Norway's Carbon Tax	British Columbia's Carbon Tax	Australia CPM	Mexico Carbon Tax
General Information				
Jurisdiction	National	Subnational	National	National
Start Date	1991	2008	2011	2014
Compliance Period Duration	-	Phase 1: 2008-2012 Phase 2: 2013-2018 (tax freeze)	1st period: 2012-2014 2nd: 2015-2018 3rd: 2018- … (switch to an ETS)	1st period: 2014-2018 2nd period: 2018-… (switch to an ETS)
Regulating Authority	Norwegian Tax Administration, Norwegian Petroleum Directorate	Ministry of Finance	The Clean Energy Regulator, the Climate Change Authority, and the Productivity Commission	Ministry of Environment and Natural Resources and Ministry of Finance
Offset	Norway is also included in the EU ETS	Offset is possible from the Forest Carbon Emission Offsets Project & Atmospheric Benefit Sharing Policy	Offsets from the Carbon Farming Initiative (CFI) can be used for compliance under the CPM, subject to a 5% limit during the fixed-price period	Allows for use of CER offsets. ETS launched in 2018
Pricing Setting				
Initial Tax Rate	\$ 4-54/tCO_2e (2014)	\$10.19 (2008)	\$23.39 (2012)	\$3.50 (2016)
Annual Escalator	None	Yes (\$5 per year until max tax rate of \$29.35, 2012)	Yes (5% per year)	None
Current Tax Rate per ton of CO_2e (USD nom)	\$4-\$54 (2016)	\$21.61	\$21.34 (2016)	\$3.50 (2016)
Tax Compliance	Failure to comply with the law is subject to fines and up to three months imprisonment	The Ministry of Finance has been given significant inspection and audit powers, with the ability to assess interest and penalties (ranging from 10–100% of the tax amount owed)	The Clean Energy Regulator Has the authority to enter and inspect the property of regulated entities (if he suspects efforts to violate the Act), besides having the authority to order an audit of the reporting of a regulated entity's emissions	The Federal Attorney General's Office for the Protection of the Environment can impose a fine of 3,000 days of minimum wage for a violation

Sectorial Coverage				
Point of Taxation	Upstream and Midstream	Downstream	Electricity and gas were taxed Midstream. Other emissions were taxed Downstream	Upstream
Tax Type	Carbon content of select fuels	Emissions-based	Emissions-based	Carbon content of select fuels
Sectorial Coverage	Petroleum extraction, HFC/PFC importers, oil, natural gas and LPG suppliers	Most economic sectors, with exemptions like wood/biomass, biomethane, fuel to be exported, emissions resulting from industrial processes (unrelated to fuel use), among others	Power stations using nonrenewable energy sources, other stationary electricity generation sources, fugitive emissions, industrial processes, transportation, and landfills	Fuel producers and importers
Fuels Covered	Heating oil, diesel, natural gas, gasoline, LPG	23 fossil fuels, like coal, oil and natural gas	Gasoline, diesel, natural gas, fuel oil, propane and coal	All fossil fuels (sales and imports of propane, butane, gasoline, kerosene, fuel oil, petroleum coke, carbon coke, and coal), except natural gas
GHG Covered	CO_2, CH_4, HFC, PFC	CO_2, CH_4, NO_2, SO_2, HFC, PFC	CO_2, CH_4, NO_2, SF_6, HFC	CO_2
Overall Emissions Coverage	80%	70%	60%	40%
Carbon Leakage				
EITE Protection and Exemptions	Exemptions for international air and maritime transport, exported gas, freight and passenger transport within domestic shipping sector. Industrial processes are exempt from the carbon tax but since 2005 have been partly covered by the Norwegian ETS, which has been linked to the EU ETS since 2008. Since 2013, industrial processes have been fully covered by the EU ETS	Exemptions for fuel exporters, International travel, non-fossil fuel GHG emissions from industrial processes, i.e., cement, landfills, forestry, and agriculture. A revenue-neutral carbon tax design with broad-based tax reductions for businesses helps address carbon leakage and promote cost containment	Provisions of significant assistance to EITE entities through a system of free permit allocation known as the Jobs and Competitiveness Program. Some activities marked by very high carbon costs received very high levels of assistance (covering 94.5% of the industry average carbon costs)	Natural gas exempted
Carbon Revenue Method				
Revenue Generated	$670 million (2016)	$5.01 billion (2008–15)	$6 billion (2013-2017)	$1.22 billion (2014–16)
Revenue Disbursement	Revenue directed toward the Global Government Pension Fund and national budget	Revenue neutral (business & personal income tax cuts, low-income tax credits, direct grants to rural and native communities)	At least 50% of the revenues generated went toward a Household Assistance Package—financial assistance for pensioners and low-income households. Around 40% of the revenues were to be allocated toward a Jobs and Competitiveness Package—a number of assistance measures for the business community to make the transition to a clean energy future	Revenue is directed towards the national budget

2.3.3. Lessons for Brazil

From the four ETS designs reviewed (EU ETS, California Cap-and-Trade, NZ ETS, and China ETS), several design features that enable successful initiation and management of the ETS marketplace were identified. An ETS, rolled out with dynamically adjustable emission caps based on stakeholder feedback and new emissions data (e.g., Chinese pilots), has been shown to result in price stability and cost-effective emissions reductions. An ETS rolled out with ambitious coverage and free allowances seems to be initially more politically palatable, but transitioning to auctioning of allowances over time (e.g., California and EU ETS phase 3) ensures simultaneous revenue generation.

Getting firms used to reporting data prior to the rollout of an ETS may help regulators avoid over-allocation for a given ETS period. Similarly, developing scenarios for future projections can also be useful to anticipate different types of events that could affect the system (e.g., the financial crisis affecting the estimates of EU ETS emissions).

A price floor/ceiling (or "collar") creates a more stable market with less price volatility (e.g., California Cap-and-Trade) and may lower compliance costs in the long run. Restricting banking of allowances or not allowing borrowing between phases (e.g., EU ETS) may lead to a collapse in allowance prices at the end of a commitment period if allowances are over-allocated. The presence of reserve allowances with an independent regulatory body enables the government to intervene quickly in the market if necessary (e.g., California's CARB), to manage liquidity and or implement a price collar.

International linkage benefits smaller markets by reducing abatement costs, increasing liquidity, and achieving cost effectiveness. Soft linkages to offset markets without a cap on such offsets can result in excess supply and price collapse (e.g., NZ ETS).

Overall, managing the level of price caps, the percentage of banking and borrowing between phases, the amount of reserve allowances, and the ability to adjust these levers quickly in the market could ensure a predictable marketplace with stable prices and sufficient liquidity (PMR and ICAP, 2016). Finally, most countries that have implemented a carbon price have done so in the presence of complementary policies including renewable portfolio standards, fuel efficiency standards, feed-in-tariffs, and investments in innovation. The presence of complementary policies can achieve significant emission reductions but contribute to an overabundance of supply in the ETS market, which places downward pressure on the permit prices (SCHMALENSEE and STAVINS, 2015).

From the four carbon tax systems (Norway's Carbon Tax, British Columbia's Carbon Tax, Australian CPM, and Mexico Carbon Tax) analyzed, some key design features necessary for the efficient operation of a carbon tax program were identified. Low tax rates per ton of CO_2 (e.g., Mexico) with no mechanisms to increase the future tax rate may reduce and eventually nullify the price effect of the tax on emission reductions over time. An ambitious or escalating tax rate per ton of CO_2 (e.g., British Columbia and Norway) is necessary for substantial emission reductions outcomes, but may not be sufficient if many exemptions are provided and/or the structure of the economy poses inelastic demand for sectors/fuels taxed (e.g., the oil and gas sectors in Norway).

In addition, a clear, stable, and steady tax rate increase is necessary to drive deeper emission reductions, as well as to send transparent market signals to private actors that climate policy is a long-term and economy-wide policy. Exempting emission-intensive trade competitive sectors (e.g., shipping in Norway and natural gas in Mexico, and industry in the four experiences) from carbon taxation undermines the purpose of a carbon tax. Exempting certain sectors may make the introduction of a carbon tax politically feasible though. In such cases, combining the price effects of carbon taxes with investments through the earmarking of funds in clean energy technologies could result in more progressive emissions reduction. Earmarking funds from carbon taxes towards energy efficiency or renewable energy investments are only effective if a sound complementary policy framework for using the earmarked revenue exists (e.g., green spending capital in Norway).

Failure to define a consistent policy framework and adhere to it may result in carbon tax revenues not being dedicated to investments in either innovation or emissions reductions, even if they are being put towards other social goods (e.g., Mexico's carbon tax).

For systems that impose both a carbon tax and ETS across sectors (for instance, Norway and Mexico), it is important to identify whether there is an overlap of carbon tax and ETS on the same emissions base (e.g., the electricity and industrial sectors in Norway) and ensure that the overlap does not have distributional consequences or lead to increased, economically-inefficient abatement costs. From the international experience, some CPI begin as carbon tax and then became (or starts to interact) with an ETS (e.g., Mexico).

Finally, taxing upstream at the point of fuel extraction (e.g., Norway) or downstream at major emitting entities (e.g., British Columbia) reduces the complexity of a carbon tax design and enforcement, making it more feasible for low developed countries with less well-developed administrative states.

2.3. Addressing Competitiveness Risks and Mitigation Policies for Carbon Leakage

A series of impacts should be analyzed in order to reduce the competitiveness risks of the sectors. In this sense, mitigation policies must be considered as an alternative to those sectors most impacted by the implementation of a CPI.

2.3.1. (Possible) Effects of Carbon Pricing and Competitiveness Risks

The introduction of a CPI can have a number of effects and impacts on the economic sectors, especially on the more carbon intensive ones. Certainly, such impacts can influence the competitiveness of the sector, being directly associated with some possible risks, among them economic, environmental and political, which will be analyzed below.

2.3.1.1. Economic Risks

When a regulatory climate policy is introduced that affects only a subset of economic agents, two types of substitution effects take place in the market (JUERGENS, BARREIRO-HURLÉ and VASA, 2013). The first type of substitution effect occurs in the domestic market and is policy-driven, such that products with higher carbon intensities face higher production costs and thus become relatively more expensive than their low-carbon substitutes. Therefore, demand/cross-price elasticities will govern any potential demand change for a given (group of) product(s), leading towards a less carbon-intensive consumption bundle.

The second type of substitution effect occurs in the international market and is known as ‘carbon leakage’. It is an unintended by-product of policy that undermines the very objective of the policy itself (namely, protecting the global environmental good of the climate) and should therefore be avoided. Carbon leakage refers to emissions that are displaced rather than reduced, as a result of unilateral action on climate change in a region. It is a secondary or spillover effect of carbon pricing, and affects the environmental effectiveness of a unilateral carbon pricing policy (IPCC, 2007). Concerns around the potential for carbon leakage remain at the forefront of debate.

Carbon leakage occurs when production shifts from a carbon-constrained region to those regions that do not have such constraints, so that formerly domestically produced products are substituted by relatively cheaper-imported products. This reduces economic activity, but does not change the consumption bundles. It remains a controversial issue according to the Climate Change Negotiation Conference given the emergence of a growing number of regional ETSs with a unilateral pricing mechanism for carbon emissions (SATO et al., 2015).

The impact of a price on carbon will also differ across industries depending on the extent to which they use energy, and fossil fuel energy in particular, as a production input. ALDY and PIZER (2015) find that energy-intensive industries bear much larger adverse output impacts than non-energy-intensive industries under this climate policy, ranging from 3 percent to 5 percent for steel, chemicals, aluminum, cement, bulk glass, and paper industries. The changes in production under the carbon price of $15 per ton carbon dioxide price are dwarfed by annual variation in output in energy-intensive industries.

An explicit assessment of net imports could then shed light on the extent to which a carbon price would result in adverse competitiveness effects rather than simply a reduction in domestic consumption. ALDY and PIZER (2015) show that the increase in net imports is much smaller than the decline in production under a carbon price. Only about one-sixth of the fall in production – less than 1 percent – is associated with increasing net imports for the most energy-intensive industries. When accounting for the change in net imports, the employment impacts amount to less than 4,000 jobs under a $15/t$CO_2$ carbon price (ALDY and PIZER, 2014).

These results have two important implications for the design of competitiveness policies. First, given that only the most energy-intensive industries bear statistically significant impacts from pricing carbon, cost-effective competitiveness policies would target those energy-intensive industries (ALDY, 2016). Second, the economically modest impacts of a carbon price on net imports suggest that the economic benefits of targeted competitiveness policies may also be relatively modest.

These competitiveness effects have more than just economic consequences. According to JUERGENS, BARREIRO-HURLÉ and VASA, 2013, the potential for relocating emissions-intensive activities to unregulated countries would result in higher emissions in these countries than they would have experienced otherwise. This “emissions leakage” would undermine the environmental benefits of the domestic climate policy and lower societal welfare. Moreover, implementing a public policy that results in both job loss and lower-than-expected environmental benefits could weaken public and political support for mitigating greenhouse gas emissions.

2.3.1.2. Environmental Risks

Suppose that a domestic carbon price leads industry A to shut down in country 1, while a new industry A capacity comes in country 2, which does not impose a carbon price on its energy-intensive manufacturers. Global industry A production would remain unchanged, but a larger fraction of its global capacity would operate in markets not subject to a carbon price. The emissions from country 1 associated with industry A would have shifted to country 2, resulting in no environmental benefit associated with job loss and production decline of closing that facility.

This so-called emissions leakage undermines the environmental benefits of the domestic carbon pricing policy. The extent to which this form of leakage would offset domestic GHG abatement will depend in part on the fraction of an economy’s emissions subject to trade substitution. For example, ALDY (2016) points out that many sectors of the domestic economy have no foreign substitute – household heating and lighting, commuting to work, and services consumption such as entertainment, lodging, and dining, to name just a few. This form of emissions leakage will likely affect only tradables.

It is important to distinguish emissions leakage resulting from competitiveness effects from emissions leakage that may occur through other channels. For example, a domestic carbon price would raise the price of energy. As consumers respond by conserving energy, reducing energy-consuming activities, and investing in more energy-lean capital, domestic fossil fuel consumption declines relative to what it would have been in the absence of the policy (BRANGER and QUIRION, 2013). By lowering fossil fuel demand, the price for fossil fuels exclusive of the carbon price will fall. Consumers in other markets who do not face a carbon price would likely respond to the lower fossil fuel prices by increasing their consumption of these fossil fuels.

In effect, the conservation and efficiency response to a carbon price in one market weakens the incentive for such conservation in markets without a carbon price as fuel prices in global energy markets respond to the behavioral change in the markets with carbon pricing. According to SATO et al. (2015), leakage through global energy markets dominates the leakage through competitiveness effects. As a result, policies to address competitiveness effects will mitigate only a fraction of the anticipated emissions leakage from a domestic carbon pricing policy[8].

2.3.1.3. Political Risks

The competitiveness effects of domestic climate policy could pose political risks to the broader carbon pricing policy. If a climate change policy raises energy prices and drives the relocation of manufacturing capacity to developing countries, but does not meaningfully reduce GHG emissions due to leakage, then business stakeholders could criticize the policy for delivering high costs and causing job loss without environmental benefits (ALDY, 2016). Some environmental advocates who oppose carbon pricing policies may also use the prospect of such an outcome to criticize the domestic policy with the intent of refocusing mitigation efforts on command-and-control regulations.

This illustrates the importance of empirical analysis in informing the political debate on carbon pricing. If the economic and environmental impacts of competitiveness are small, then that has different political implications than if they were quite large. Moreover, stakeholders may conflate, or at least not differentiate between, the competitiveness effects from the domestic consumption impacts. Finally, the political dimension of competitiveness suggests that stakeholders could be invited to contribute their own analyses of competitiveness to further enrich and inform the discussion of policy needs, policy design, and subsequent implementation.

The costs of climate policies may negatively affect domestic firms if their competitors do not face comparable emissions regulation or taxation. In particular, energy-intensive manufacturing

[8] The exception is in the case of policy efforts through multilateral negotiations to ensure that all trade partners implement a domestic carbon pricing policy.

industries have expressed concerns that domestic climate change policy could impose adverse competitiveness effects because it would raise their production costs relative to those of their foreign competitors (ALDY, 2016). To be more exact, the competitiveness effect reflects the impacts of the differential in carbon prices or the effective gap in the shadow price of carbon between two domestic climate programs on those countries' net imports. Thus firms operating under the higher carbon price experience adverse competitiveness effects if their domestic or foreign market share declines. In turn, this could result in lower production, job loss, and relocation of factories and related operations to countries without a domestic climate policy (TRACHTMAN, 2015; JAFEE et al. 2009).

2.3.2. Mitigation Policies for Carbon Leakage

The primary benefit of a well-designed competitiveness policy is that it would mitigate and potentially eliminate the competitiveness risks. Nonetheless, competitiveness policies also carry risks, in terms of their potential impacts on the distribution of the benefits and costs of carbon pricing policy, the efficiency of pricing carbon, and international relations in multilateral trade and climate policy contexts.

When addressing this challenge, there are two key (and interrelated) questions that policy makers need to consider (PMR, 2015):

- Which sectors should be targeted (supported) by the leakage prevention mechanism?
- What form should that leakage prevention mechanism take?

As a matter of fact, most carbon pricing policies include provisions to compensate regulated sectors for the cost of compliance (SATO et al., 2015). They could impose tariffs reflecting the embedded carbon emissions in imports, such that domestically produced goods and their foreign competitors face a common carbon price (WEISBACH, 2015; AGAN et al. 2015). Climate policy could direct benefits to potentially vulnerable firms, such as through free allowance allocations in cap-and-trade programs or targeted tax credits (GRAY and METCALF, 2015). Some northern European carbon tax programs have explicitly exempted energy-intensive manufacturing from their carbon tax (ALDY and STAVINS, 2012). Policymakers could work through multilateral negotiations to ensure that major trade partners undertake comparable domestic emissions mitigation policies. They could take such multilateral coordination a step further by linking domestic mitigation programs among trade partners, which could then yield a common carbon price for businesses operating under all linked programs.

These policy options, however, carry their own risks. They may run afoul of current obligations under the World Trade Organization – WTO (TRACHTMAN, 2015). The design of such policies may result in a loss in social welfare and limit the ability of the government to offset potentially regressive impacts of pricing carbon. Competitiveness policies may also have important implications for ongoing international climate negotiations. Finally, the choice and design of competitiveness policies may entail political risks that could also weaken support for the broader domestic climate change policy program.

2.3.2.1. Free Allowance Allocations

Industrial sectors at risk of carbon leakage have mainly been assessed via modelling analysis and the single-country assessment method (SIJM et al., 2004; BARKER et al., 2007; HOURCADE et al., 2007; DEMAILLY and QUIRION, 2008). These studies focus on the influence of ETS on the economic benefits and trade performance of industrial sectors. The results of modelling analyses can also be applied by policy makers to design appropriate allocation approaches that compensate vulnerable industrial sectors for their profit losses (WANG et al., 2017).

With ETS, the favored approach is to exempt certain sectors deemed at risk of carbon leakage from auctioning, and instead distribute the emission allowances to these sectors for free. Determining which businesses are at risk is difficult, however, not least because of the problem of asymmetric information on compliance costs between the regulator and the regulated (SATO et al., 2015). Free allocation can also imply very large rents; hence the allocation process is prone to rent-seeking behavior and large-scale lobbying by industry (GRUBB and NEUHOFF, 2006). In addition, policy makers may also be motivated by concerns other than carbon leakage – e.g. employment and investment migration – to protect sectors from the impact of carbon prices.

In general, free allocation for direct emissions is the main carbon leakage risk mitigation measure currently in place throughout the world (MARCU et al., 2014). The EU, Australia, California, Quebec and New Zealand all use varying forms of free allocation. While the emissions permits received free of charge can be used for compliance purposes, the incentive to reduce emissions is still present. Any surplus permits resulting from actions to reduce emissions in a given installation can be sold in the market, and provide additional revenue. What needs to be kept in mind is that the goal is to mitigate the risk of carbon leakage arising from the need to purchase emissions permits in order to meet compliance obligations from direct emissions.

Allocations can either vary quickly as firm output levels change or they can stay fixed in the short-to-medium term. At one extreme, allocations can increase or decrease in proportion to a firm's output from one year to the next. At the other extreme, allocations are determined according to the firm's output in a historical period and left unchanged for an extended period. In practice, most schemes either update allocations annually, as in California, New Zealand, Australia, and Kazakhstan, or after a period of three or more years, as in the first two phases of the EU ETS and most of the recent Chinese ETS pilots (ICAP, 2018).

In addition, the amount of allowances a firm receives can either reflect its actual emissions or be linked to a predefined "benchmarked" emissions intensity. According to PMR (2016), the former approach is normally implemented through providing allowances that are some proportion of the firm's total emissions. By contrast, a benchmarking approach severs the link between a firm's own emissions and the allowances it receives. Instead, under this approach, a sector-wide assessment of "appropriate" emissions intensity is made for all firms in the sector, and firms receive allowances in some proportion to their output multiplied by this benchmark. Firms that have emissions intensity lower than the benchmark are advantaged and receive (proportionally) more allowances than firms that have an emissions intensity higher than the benchmark.

According to PMR (2015), the main ETS designs for facing carbon leakage are:

- provision of free allowances allocated on a grandfathering approach, where allocations are proportional to an individual firm's historical emissions and there is no rapid adjustment if firms change their output;
- fixed sector benchmarks (FSB), where allocations of free allowances are based on product-specific benchmarks (as with output-based allocation) but without rapid adjustment if there are future changes in output (as with grandfathering);

- output-based allocations (OBAs) of free allowances, where allocations are based on product-specific benchmarks and changes in output lead to rapid changes in allowance allocations;

Grandfathering approach appears attractive as it should influence firm behavior and abatement incentives, and because of its relative ease of implementation. Under a pure grandfathering scheme, firms would receive assistance directly related to their historical emissions, and the amount would remain independent of future output decisions or decisions to reduce their carbon intensity. This means that grandfathering continues to provide firms with a strong incentive to reduce their emissions intensity. It can therefore sell the surplus allowances and use the profits to pay off its abatement investment (GRUBB and NEUHOFF, 2006). This feature, combined with the relative simplicity of working out how much assistance to provide each firm, has made it a popular method of providing assistance in the initial stages of many carbon pricing schemes (PMR, 2016). Prominent examples include the first two phases of the EU ETS and various Chinese ETS pilots.

However, if this reduction in output is associated with an increase in output from uncovered firms then output leakage – and hence some degree of carbon leakage – is likely to occur. In turn, this means that grandfathering may not be the allocation method that minimizes the cost of meeting a given emissions reduction target in cases where carbon leakage risk is significant (FISHER and FOX, 2004). This is the reason why no carbon price scheme has involved a pure grandfathering allocation approach for the specific purpose of addressing carbon leakage.

In order to address these concerns, of greatest importance is updating. Rather than maintain assistance levels indefinitely, schemes tend to revisit allocation decisions periodically (PMR, 2016). This typically takes place every three years, including in the case of first phases of the EU ETS, as well as in the various Chinese pilot ETSs: Beijing, Chongqing, Guangdong, Hubei, and Tianjin[9]. In addition, schemes have tended to implement closure rules. Whereas under pure grandfathering, firms would be entitled to retain assistance indefinitely, even if they closed down with closure rules, continued entitlement to free allowances is made contingent on maintaining a minimum level of production.

[9] The Chinese ETS is structured in phases. It is plausible that the allocation approaches of each scheme will be revisited for future phases. Future phases may or may not retain a grandfathering approach.

The second approach, **fixed sector benchmarks (FSB),** combines two features: as with grandfathering, assistance levels do not vary quickly and smoothly as firms change their level of output and emissions; in contrast to grandfathering, the level of assistance is determined by reference to a product or sector-level benchmark emissions intensity rather than by reference to the current or historical emissions (intensity) of each individual firm. Crucially, by severing the link between the emissions intensity of the firm and the allowances the firm receives, benchmarking better preserves incentives for firms to improve their emissions intensity than grandfathering (GRUBB and NEUHOFF, 2006).

In broad terms this is the approach adopted in Phase III of the EU ETS. A series of benchmarks were created for different activities under the cap, and the free allowances received by firms/installations in the sector were set by multiplying the firms'/installations' historical output level by the benchmark (plus a further downward adjustment). However, once the level of free allowance was set, future changes in firm/ installation output had limited impact on the allowances received by each firm/installation (PMR, 2015, 2016).

From an economic perspective, the stringency of a FSB benchmark will have a minimal effect on incentives to reduce emissions and is largely a distributional question. In principle, regardless of where the benchmark is set, firms should have the same marginal incentive to reduce their emissions intensity (FISHER and FOX, 2004). It should be immaterial whether a firm is more or less efficient than implied by the benchmark: if firms that are more emissions-intensive than the benchmark reduce their emissions intensity they will face a reduced carbon emission cost net of allocations. If they are less emissions-intensive than the benchmark, a further reduction in their emissions intensity would result in an excess of allowances, which they could sell. This would imply that the level of the benchmark in the short run should not affect efficiency incentives, but does determine the allocation of resources between shareholders and taxpayers, who forgo revenue from auctioning allowances.

The calculation of benchmarks is data-intensive and creates potential for lobbying around the allocation methodology, but is feasible. As with grandfathering, an FSB approach will be dependent on closure rules and updating to be very effective in addressing leakage and this approach also carry a risk of delivering windfall gains if applied to sectors that are not exposed to leakage.

The last approach, **output-based allocations (OBA)**, has two key properties: assistance is allocated according to a predetermined benchmark of emissions intensity and when firms increase or decrease their output, the amount of assistance that they receive correspondingly rises or falls, according to the predefined benchmark level of intensity.

This model is similar to the FSB approach in that the initial allowance allocation is determined by an emissions benchmark (which could be calculated in exactly the same way as the FSB approach) multiplied by the firm output level (PMR, 2016). However, in contrast to the FSB approach, if there are subsequent changes in firm output, with just a small lag there is an adjustment in the allowances that the firm receives. Variants on this basic model are used for providing assistance in California, New Zealand, previously in Australia, some sectors in Shenzhen, China.

By using benchmarks OBA preserves incentives to reduce emissions intensity in a similar manner to FSB. However, in contrast to FSB and grandfathering, OBA targets leakage more strongly, since an extra unit of output will directly result in additional allocations. This can be contrasted with grandfathering and FSB schemes where extra output does not lead to additional assistance, other than where closure or other thresholds are applied. This works to maintain or increase output levels despite the pressure of competition from firms that do not face the carbon price. As such, it offers strong leakage protection.

OBA approach could also involve higher administrative costs than benchmarking and FSB approaches, because output data must be regularly reported. In summary, OBA looks attractive where it is closely targeted at sectors genuinely at risk of carbon leakage, but it is particularly unattractive if applied too broadly.

2.3.2.2. Border Tax Adjustments

The easiest approach for a country determined to comply with high environmental standards and to apply these to imports is the introduction of a (unilateral) tax or tariff on goods from countries that have not "comparably offset" the GHG emissions associated with the goods production. Such a "penalty" can consist of a tariff or tax or in an obligation to purchase carbon credits in the country of sale, i.e. obtain emission allowances (KAUFMANN and WEBER, 2011). While tariffs apply exclusively to imported goods, taxes and border tax adjustments (BTA) – also known as border tax measures (BTM) – are based on an existing domestic charge and can apply to both imports and exports. A specific tax or flat tariff would have to be designed so as to compensate for the additional costs in connection with the application of the more stringent emissions standards, thus preserving the competitive equality between the compared products (WTO, 1997).

In principle BTAs can successfully mimic economic and environmental outcomes under a widely harmonized carbon pricing regime, indicating its broad efficiency and effectiveness (PMR, 2016). Modeling of the potential effectiveness of BCAs generally suggests that they would be effective in reducing leakage. BRANGER and QUIRION (2013) examine 25 studies and find 310 estimates of carbon leakage ratios across the various scenarios and models used. Their meta-regression analysis indicates that BTAs reduce leakage rates by around 6 percentage points on average, holding all other parameters constant. This rate is substantial given that leakage rates studied range only from –5 to 15 percent in the BTA scenarios, and 5 to 25 percent without the policy. The potential effectiveness of BTAs was also supported by analysis utilizing harmonized parameters across a variety of models through the Energy Modeling Forum; this analysis found that BTAs on average reduced leakage rates from 12 percent to 8 percent relative to a reference scenario with no BTAs or allocations (BÖHIRINGER et al., 2012).

A BTA can target imports, exports or both. By targeting both imports and exports, a BTA ensures that producers at risk of carbon leakage will not suffer a competitive disadvantage in their domestic market, or when exporting. A BTA for imports (from a less-or-not-carbon constrained jurisdiction) can be expressed as a tax, or the requirement to hold/purchase allowances. When we address exports, a rebate for the cost of carbon needs to be implemented (MARCU et al., 2014).

BTAs are seen as having both positive and negative effects, and that debate will continue. But it is important to point out that BTAs will act as an alarm system for, but not only, developing countries, which will be suspicious of these measures as being ‘green protectionism’. Some countries, specially developing ones, may argue that a border tax adjustment imposes an unfair burden on their exports. This may lead to the threat – or even the start – of a trade war. For instance, the Chinese and Indian governments have raised that spectre in the context of the UNFCCC in the case of EU ETS and international aviation. As a result, BTAs may become entangled in a long, drawn-out WTO dispute, with the accompanying uncertainty (WORLD BANK et al., 2018; PMR, 2016).

On the other hand, the prospect of a BTA could create the incentive for a country's trade partners to step up and implement their own domestic emissions mitigation programs. ALDY (2016) points out the case of the US, in which Chinese government officials have been aware of the US concerns regarding competitiveness and climate policy for quite some time. With China's pilot cap-and-trade programs setting the foundation for nationwide expansions later this decade, China is pursuing a domestic carbon pricing policy that could exempt its exports from a BTA. The outstanding question is whether a BTA becomes the norm in countries with domestic carbon pricing policies, or whether it serves as the stick, rarely used, to encourage substantial emissions mitigation programs among trade partners.

However, there are counterarguments based on the claim (i) that the implementation of BTA would be a prima facie violation of both the spirit and the letter of multilateral trade principles requiring equal treatment of like products, (ii) that the application of BTA is a disguised form of protectionism, and finally (iii) that BTA in practice undermines the principle of common but differentiated responsibilities (KAUFMANN and WEBER, 2011).

As TRACHTMAN (2015) explores in detail, there are potential legal risks under the World Trade Organization (WTO) with several of the competitiveness policies that policymakers may consider, concerning the compatibility of carbon-related BTA with the Most Favoured Nation Principle and Non-Discrimination under the General Agreement on Tariffs and Trade (GATT).

Some trade policy experts have reservations about BTA – even if it can be crafted in a WTO-consistent manner – because of the potential diplomatic and political ramifications for the relatively fragile ongoing trade negotiations. Some of the more contentious issues in the WTO fall along a developed-developing country divide, and some developing countries would perceive a BTA as targeting their export industries.

Furthermore, the political challenges may be as great, or greater, than any legal constraints. The experience of the EU in seeking to establish a regime that bore some similar characteristics to a BTA in the civil aviation sector demonstrates that the political challenges of introducing BTAs may be as, or more, significant than the legal challenges. Experts interviewed as part of the PMR (2015) study claimed that it is possible that BTAs will become more feasible when (if) a sufficient proportion of major emitters are committed to such a regime. Border adjustment measures appear more feasible when introduced by a coalition of partners who account for a significant share of world trade. The most feasible path to this outcome may be through individual action by a number of major emitters, which might then seek to harmonize their regimes through a common BTA imposed on countries outside the grouping.

In summary, BTAs perform strongly against both abatement and leakage objectives but may be politically and administratively challenging to implement. In principle they are likely to be an effective measure for preventing leakage but implementation challenges may limit their application to a relatively specific set of circumstances.

2.3.2.3. Administrative Exemptions and Tax Free Thresholds

Most carbon pricing regimes exempt some sectors or emitters through not defining the carbon price as applying to them or by setting much-reduced rates. Sometimes these exemptions are driven by practical difficulties in coverage or by broader political concerns about the sensitivity of imposing a cost on these sectors (PMR, 2015). This is often the case, for example, for small emitters, transport emissions, land use, land use change and forestry (LULUCF) emissions, waste, and agriculture emissions. However, sometimes these are also justified on the basis of concerns about leakage.

Exemptions are likely to be effective in addressing leakage and are administratively easy to implement, but fundamentally undermine the abatement incentives of carbon pricing. By reducing the effective carbon price that firms face, the risk of carbon leakage is directly reduced (BARKER et al., 2007). However, reducing the effective carbon price also means that abatement incentives are reduced in three important ways: firms have a reduced incentive to improve their emissions intensity; relatively carbon-intensive firms do not suffer a competitive disadvantage compared with firms with lower emissions intensities; and product prices of carbon-intensive goods will not rise in a way that stimulates demand-side abatement.

A prominent example of the proposed use of administrative exemptions to address leakage is under the proposed South African carbon tax. While all entities under this regime are expected to receive a basic 60 percent exemption irrespective of their exposure to leakage, exemption rates can be increased by up to 10 percent for firms that have high trade exposure plus a further 10 percent for organizations that have a high proportion of process emissions (considered difficult to reduce). Firms will also be entitled to use offsets for up to 5-10 percent of their emissions liability (GRAY and METCALF, 2015). It is expected that, over time, these exemptions will be gradually withdrawn. Policy makers anticipate that a withdrawal of exemptions may be an easier way to increase the marginal tax rate faced by firms than a straightforward increase in the nominal rate.

All entities under this regime receive a basic 60 percent exemption. Of more relevance to leakage, this regime makes a modest adjustment of exemption rates of up to 10 percent on the basis of trade exposure, and of up to 10 percent where a sector has a large portion of process emissions. The former provision directly addresses the trade driver of leakage, while the latter provision works on the logic that these emissions are harder to abate, which is a potential driver of leakage. While these provisions may broadly target leakage, they do so at the cost of preserving abatement incentives. The proposal to adjust the core 60 percent leakage rate by up to 10 percentage points to reward more efficient producers may have some effect in retaining abatement incentives, but its effect on leakage is unclear (PMR, 2015).

In general, exemptions for the purposes of leakage prevention are most likely to be necessary when establishing a carbon pricing regime and should be accompanied by in explicit plan to phase them out. This thinking underpins the South African carbon tax; the current policy proposal is to reduce the basic exemption rate from 2020, therefore increasing the carbon pricing signal. As any phase-out occurs it may be that further changes are required to ensure that South Africa's leakage protection measures are effective and sufficient to address economic concerns about leakag and any consequential political concerns.

2.3.2.4. Output Based Rebates

Sometimes policymakers aim to reduce the leakage risks associated with carbon prices by reducing other taxes paid by industry, or providing other subsidies to industry, often by an equivalent amount. This is an approach most commonly adopted in countries pursuing a carbon tax regime. The intention is to discourage carbon emissions while not increasing the overall tax liability faced by industrial firms.

Under a carbon tax regime, rebate mechanisms can be designed to emulate the properties seen under the free allowance benchmarking options. An output-based rebate, such as that used in the case of the Swedish NO_x charge, provides very similar properties to OBA; alternatively, lump-sum rebates would resemble FSB approaches (PMR, 2015). Rebates through reductions in corporate income taxes or employer social security contributions represent an alternative that may reduce the risk of leakage without reducing incentives to reduce emissions. Given these similarities to the free allowance alternatives, the trade-offs between the different approaches, and the circumstances in which any one approach might be preferred, are also similar.

For instance, in the UK, the introduction of the Climate Change Levyv – a tax on industrial consumption of different fossil fuels – was intended to offset a reduction in national insurance contributions for those affected by the tax (SUMMER et al., 2009). In Denmark, increases in energy taxes during the 1990s were accompanied by a reduction in the required employers' contributions to the additional labor market pension fund, as well as a reduction in employers' national insurance contributions (IEEP, 2013).

There is a wide diversity in the implementation of this approach. Options differ depending on the tax/subsidy base through which the revenues are recycled – for example, output in the case of the Swedish NO_x tax, and employment in the case of the UK Climate Change Levy. It can also differ depending on whether the revenues from the carbon tax are first explicitly calculated and then the rebate provided (to guarantee revenue neutrality at the government level), or whether the offsetting tax/subsidy change is introduced simultaneously, based only on an estimate of the expected revenue effects of the different fiscal changes.

For these reasons, the impact of reducing other tax rates on preventing leakage will depend very heavily on the specific design. As noted above, there are many different ways in which these schemes can be designed. The most important feature in the context of leakage prevention is the way in which revenues are subsequently recycled.

2.3.2.5. Complementary Measures

These measures include cash transfers to offset some of the carbon emission costs firms face, direct support for emissions-reduction projects, and energy efficiency measures. While these measures may be valuable in helping to deliver emission reductions, they typically have only an indirect impact on leakage and are unlikely to obviate the need for more integrated approaches (PMR, 2015).

Moreover, there are other alternatives such as subsidies to affected sectors to improve technologies, support for R&D, and adjustment of other taxes.

2.3.2.6. Comparative Analysis

From the above discussions, it can be concluded that policy makers must weigh the specific advantages and disadvantages of each leakage prevention measure in the context of their particular circumstances.

Of the free allocation approaches, those that utilize benchmarking (either OBA or FSB) are generally preferable to providing free allowances on a grandfathered basis. The attraction of both approaches is that they sever the link, which exists under grandfathering, between a firm's own historical emission levels and its free allowance allocation.

BTAs arguably perform most strongly on grounds of abatement incentives, but face political, administrative (and, possibly, legal) challenges. They are particularly appealing in that they simultaneously offer the potential to remove the competitive distortion associated with asymmetric carbon pricing, while also ensuring that the firms with the lowest carbon intensities are at a competitive advantage, and also ensuring that demand-side abatement incentives are maintained. However, their application to carbon regulation remains largely untested. They appear more likely to be feasible when introduced by a coalition of partners who account for a significant share of world trade.

At the other end of the spectrum, exemptions perform most weakly in terms of abatement incentives but will be the easiest to implement. They are likely to be appropriate only as an interim measure to ensure sufficient support for carbon pricing when a scheme is in its infancy.

Under a carbon tax regime, rebate mechanisms can be designed to emulate the properties seen under the free allowance benchmarking options. An output-based rebate, such as that used in the case of the Swedish NO_x tax, provides very similar properties to output-based allocation; alternatively, lumpsum rebates would resemble FSB approaches.

Table 5 provides a summary of the different integrated policy measures that can be used to reduce the risk of carbon leakage.

Table 5 – Summary of different mitigation policies
Source: Own elaboration based on PMR (2015)

Feature	Free Allowance Allocation			Exemptions	Rebates	Border Tax Adjustments (BTA)
	Grandfathering	Fixed Sector Benchmarking (FSB)	Output-based Allocations (OBA)			
Leakage prevention	Weak, unless closure rules and updates included	Weak, unless closure rules and updating included	Strong	Strong	Depends on design	Strong
Incentives to improve emissions intensity	In principle strong, but diluted when updates included	Preserved	Preserved	Not preserved	Preserved	Preserved
Administrative complexity	Easy to implement	Some complexity in establishing benchmarks	Some complexity in establishing benchmarks and costs in collecting output data	Easy to implement	Some complexity	Very complex
Risk of windfall profits	Some risk	Some risk	No	No	No	No
Political and legal challenges	No	No	No	No	No	Yes

3. Brazilian Climate Policy and the National Industry

The Brazilian industry is a very strategic sector, considering its representativeness in terms of GDP, employment and income generation, as well as its impact on the national trade balance (HENRIQUES et al., 2010; BAJAY et al., 2010). In this context, discussions related to the implementation of CPI in the industrial subsectors always bring up the possibility of (negative) impacts on economic dynamics, especially in the most energy-intensive subsectors. Therefore, a deep evaluation of the industrial sector is necessary.

This chapter is divided into four sections. The first seeks to present the main discussions that relate the industrial sector to the Brazilian climate policy. The second and third sections perform an economic characterization of the sector, besides their emissions profile. Finally, the fourth section maps and analysis the existing sectorial policies.

3.1. Brazilian Climate Policy and National Discussions about CPI

In Brazil, the National Policy on Climate Change (NPCC) promulgated through Law 12,187 of December 29, 2009 is the regulatory framework that guides the government under the climate change institutional arrangement. Among others, it aims to reduce anthropogenic GHG emissions and strengthen carbon removal through national sinks and foster measures that promote adaptation to climate change. Article 12 of the NPCC specifically states that the country has adopted GHG mitigation targets from 36.1% to 38.9% of its 2020 projected emissions as a voluntary commitment (BRAZIL, 2009). This objective is to be achieved through sectorial plans for adaptation and mitigation of climate change that take into account the specificities of each sector.

Brazil is also implementing its NPCC through a broad range of integrated policies and programs, including command-and-control measures, economic incentives, and public and private investments. In addition to the expected engagement of the private sector, these policies and programs will require significant amounts of public resources by 2020 (CEBDS, 2017, BRAZIL, 2015a). Changes in the emissions profile and potential new mitigation policies for the post 2020 period indicate the need to explore new economic instruments.

More recently, the Brazilian government presented its NDC at COP 21 in 2015, whose main result was the establishment of the Paris Agreement. Through this document, Brazil indicated the intention of reducing GHG emissions by 37% below 2005 levels by 2025, with a subsequent indicative contribution to reduce emissions by 43% below 2005 levels by 2030. It is economy-wide, it covers the post-2020 period, and its implementation period corresponds to successive cycles of 5 years (BRAZIL, 2015b). This cycle – which will begin after 2020 – was proposed by the country during COP 20, held in Lima, Peru, in 2014, resulting in a mitigation commitment by 2025 and an indicative contribution by 2030, aiming at the predictability of economic agents. The proposal was justified in providing greater flexibility in relation to estimates of intended contributions and possible future adjustment, considering that the new agreement would likely include processes for reviewing the overall mitigation effort already before 2025 (BRAZIL, 2015b).

For the purposes of presentation of NDC at the international level, no sector commitments were reported. The national territory was covered in the Brazilian NDC, and it was up to the government to define, at the domestic level, which sectors it intends to prioritize, as well as the policies and actions to implement. However, for internal purposes, in the process of quantifying the national contribution, the level of effort expected to be obtained from each sector for planning and considering the feasibility of the mitigation contribution was indicated (BRAZIL, 2015a,b).

The mitigation component of the Brazilian NDC was constructed based on national circumstances and took into account initiatives for the three sectors with the largest participation in the Brazilian emissions profile in 2012 (Land Use Change and Forestry, Energy and Agriculture). It took as a basis the total quantification of the national contribution for compliance by 2025 (and, as an indication, until 2030), but not limited to these initiatives. They are (BRAZIL, 2015b):

i) increasing the share of sustainable biofuels in the Brazilian energy mix to approximately 18% by 2030, by expanding biofuel consumption, increasing ethanol supply, including by increasing the share of advanced biofuels (second generation), and increasing the share of biodiesel in the diesel mix;

ii) in land use change and forests:

- strengthening and enforcing the implementation of the Forest Code, at federal, state and municipal levels;

- strengthening policies and measures with a view to achieve, in the Brazilian Amazonia, zero illegal deforestation by 2030 and compensating for greenhouse gas emissions from legal suppression of vegetation by 2030;

- restoring and reforesting 12 million hectares of forests by 2030, for multiple purposes;

- enhancing sustainable native forest management systems, through georeferencing and tracking systems applicable to native forest management, with a view to curbing illegal and unsustainable practices;

iii) in the energy sector, achieving 45% of renewables in the energy mix by 2030, including:

- expanding the use of renewable energy sources other than hydropower in the total energy mix to between 28% and 33% by 2030;

- expanding the use of non-fossil fuel energy sources domestically, increasing the share of renewables (other than hydropower) in the power supply to at least 23% by 2030, including by raising the share of wind, biomass and solar;

- achieving 10% efficiency gains in the electricity sector by 2030.

In addition, Brazil also intends to:

iv) in the agriculture sector, strengthen the Low Carbon Emission Agriculture Program (ABC) as the main strategy for sustainable agriculture development, including by restoring an additional 15 million hectares of degraded pasturelands by 2030 and enhancing 5 million hectares of integrated cropland-livestock-forestry systems (ICLFS) by 2030;

v) in the industry sector, promote new standards of clean technology and further enhance energy efficiency measures and low carbon infrastructure;

vi) in the transportation sector, further promote efficiency measures, and improve infrastructure for transport and public transportation in urban areas.

Table 6 below presents the emission estimates made for the years 1990, 2005, 2025 and 2030, based on the assumptions adopted in the actions described above.

Table 6 – Emissions per sector (millions tCO_2e – GWP[10] 100)
Source: Own elaboration based on BRAZIL (2015a)

Sector		1990		2005		2025		2030	
Energy		194	14%	332	16%	598	44%	688	57%
Livestock		356	25%	484	23%	470	35%	489	40%
Forestry and LULUCF	Emission	826	58%	1.398	66%	392	29%	143	12%
	Remotion	-	-	211	10%	274	20%	274	23%
	Liquid	-	-	1.187	56%	118	9%	-131	-11%
Industrial Process		48	3%	77	4%	98	7%	99	8%
Waste Treatment		12	1%	54	3%	61	5%	63	5%
Total		1,436		2,133		1,346		1,208	
Reduction in relation to 2005		-		-		37%		43%	

As stated in the NDC document, regarding the industrial sector, there are neither details nor precise quantifications. Brazil’s NDC only mentions that the industrial sector should promote mitigation actions based on new clean technologies standards, energy efficiency measures and low carbon infrastructure. However, the NDC document also considers the use of economic mechanisms, but it is not clear about the configuration of the Brazilian climate policy in terms of economic instruments for carbon pricing.

Therefore, an issue becomes relevant when looking at the Brazilian NDC: how will the national climate policy be shaped in terms of economic mechanisms and instruments for carbon pricing? As stated in the NDC document, "Brazil reserves its position regarding the possibility of using any market mechanisms that may be established under the Paris Agreement" (BRAZIL, 2015b). Furthermore, article 5 of the NPCC states that "the use of financial and economic mechanisms that are national in scope and referring to mitigation and adaptation to climate change" will be encouraged, and it is emphasized in article 6 that such mechanisms are among those already existing within the framework of the

[10] *Global Warming Potential*.

UNFCCC, which must present environmental standards and quantifiable and verifiable targets (BRAZIL, 2009).

In the same article, more specifically in item VI, there is a reference to the possibility of adopting a tax. According to the paragraph, "fiscal and tax measures to encourage the reduction of emissions and removal of greenhouse gases, including differentiated rates, exemptions, compensations and incentives, to be established in a specific law" may be used. It should be highlighted that any attempt to tax emissions faces the resisteance, given the unpopularity of increasing the tax burden on citizens and companies (PEREIRA and BERTHOLINI, 2017). However, the country already has a legal framework developed regarding the use of economic instruments as mechanisms for environmental protection, besides having experiences on destining part of taxes collected for social and environmental purposes – for example, Ecological Tax on Circulation of Goods and Services (Ecological ICMS) and Contribution of Intervention in the Economic Domain – Fuel (CIDE Fuels).

Nonetheless, in article 4, item VIII, it is affirmed that "the development of the Brazilian Emission Reduction Market (MBRE) will be fostered" (BRASIL, 2009). Another reference to the use of an ETS occurs throughout the document, specifically in article 9, which states that this market "will be operationalized in commodities and futures exchanges, stock exchanges and organized over-the-counter entities authorized by the Securities and Exchange Commission (CVM), where it will be negotiated securities representing certified greenhouse gas emissions avoided". In addition, Decree 7,390, dated December 9, 2010, which regulates some articles of the NPCC and imposes targets for GHG emissions from economic sectors, states in its article 4, item V, caption 3 that "sectorial targets may be used as parameters for the establishment of the Brazilian Emission Reduction Market – MBRE". No reference to possible fiscal or tax measures of carbon is presented in this Decree (BRASIL, 2010).

Therefore, from the analysis of the official documents essential to the design of the Brazilian climate policy, it is not clear how the national climate policy will be shaped in terms of economic mechanisms and instruments for carbon pricing to reach the goals taken on by the country. Nonetheless, the Brazilian Federal Government has shown an interest in analyzing CPI frameworks and assessing their potential impacts on the Brazilian economy (ICAP, 2018, BRAZIL, 2015a, b).

The World Bank has established the Partnership for Market Readiness (PMR) through a trust fund supported by capacity-building grants. This partnership aims to provide "implementing countries" with financial and technical support to build capacity to start structuring the main components of market readiness, such as data collection, monitoring, reporting and verification (MRV) system and/or construct pilot market instruments to define the correct scale of their mitigation efforts. The PMR also creates and shares a body of knowledge about market instruments, such as how to prepare market instruments and lessons learned.

In May 2012, the Partnership Assembly approved the allocation of funding for the preparation phase of Brazil based on what the country presented in its Organizing Framework for the Market Preparation Activities Scope. During the Brazilian market preparation proposal, the identified information gap began to be filled by studies commissioned by the Brazilian Ministry of Finance (MF) with the support of the PMR.

The MF was tasked by the Executive Group of the Interministerial Commission on Climate Change to coordinate the assessment of the suitability and feasibility of CPI and their impacts on the Brazilian economy (MF, 2014). In a first phase, starting in 2012, a multi-institutional working group (with participation of seven ministries and representatives of the various MF technical units) recommended further analysis to improve information on emissions at the level of individual facilities and effects of carbon prices through an ETS or a carbon tax.

Regarding the improvement of information on emissions at the facilities level, the objectives are: (i) to consolidate and disseminate knowledge related to the international experience in collecting and managing data for GHG emissions at the installation level and (ii) generate recommendations for the development of such a system in Brazil. Based on the analysis of various problems and experiences on the implementation of MRV systems, a working group coordinated by MF, and integrated by the Federal and State governments, delivered in February 2014 a report with an evaluation of the policy options for the establishment of a National GHG Emission Reporting Program.

Another relevant initiative is a partnership with the British Embassy in Brazil. In its first phase (2012/2013), the "Green Fiscal Policy in Brazil" project compiled existing analytical tools to assess the economic impacts of GHG emission reductions (GVCES, 2013). The second phase (2014-2015) developed a macroeconometric model to simulate the impacts of a tax reform in terms of GHG emissions, economic performance and job creation. The objective of this project was to explore the possibilities of a "green tax reform" in Brazil, with a more detailed breakdown of taxes.

The activities carried out during the preparation phase of the PMR in Brazil aimed to explore approaches to consider the economic effects of carbon pricing through an ETS or a carbon tax. Two studies were developed: (i) economic modeling of carbon pricing instruments and (ii) review of experience and recommendations for the design and implementation of a carbon tax in the country.

The first work was based on the adaptation of a computable general equilibrium (CGE) model for the Brazilian economy, called "BeGreen"; and the simulation of three policy scenarios to achieve mitigation targets in specific sectors by 2030: command-and-control; carbon prices through tradable allowances; and the carbon price through a simplified carbon tax (POLLITT, 2015). The second study provided an up-to-date review of the economic literature and lessons learned from the international carbon tax experience. The study also explored legal possibilities and design options for a carbon tax in Brazil (GVCES, 2013).

The analysis so far has been important for the MF to launch an internal process to (i) assess the possible implications of adopting carbon pricing instruments, (ii) map possible design options and apply modeling tools for economic instruments by MF staff. However, since it was still a preparatory phase, the work was mainly focused on internal discussions, with limited interfaces to other stakeholders outside the MF. As indicated by the initial studies, a more detailed modeling work would be necessary to obtain more robust results, based on policy options suitable to the Brazilian context (MF, 2014). In addition, the need for more specific analyses was emphasized, for example, in order to understanding the interaction between CPI and other sectorial policies and instruments.

In September 2014, the Partnership Assembly allocated an additional fund to Brazil for the Implementation Phase, to be used in the activities proposed in the MRP. The MRP is currently being developed, divided into three components. Component 1 consists of studies to guide the formulation of policies through two activities: (i) conducting sector studies and (ii) proposing different instrument designs. This Component is investigating the main issues involved in implementing CPI in the economics sectors/subsectors, as well as issues related to the various possible instrument designs.

The results of these studies will guide the activities carried out in Component 2 of the MRP, which will evaluate the impacts of the instruments proposed using a CGE model. A Regulatory Impact Analysis (RIA) will also be performed in this component. Finally, Component 3 will focus on sharing the results of the studies conducted in Components 1 and 2, as well as on consulting and attracting stakeholders, which should include seminars open to the public.

In the context of implementing the Brazilian MRP, the PMR Project is currently assisting the General Coordination of Environment and Climate Change of the MF's Secretariat of Economic Policy in the implementation of Component 1 of the Brazilian MRP. This includes conducting sectorial studies focusing on the electricity, fuel, industry and agriculture sectors/subsectors, as well as drawing up proposals for different CPI designs - the main instruments considered are ETS and/or carbon tax - aiming at helping assess the potential impacts of different design options. This thesis itself also wants to support this goal.

3.2. Economic Characterization

Brazilian industrialization began in the period between the two Great Wars, but it was only after the 1950s, through the Plan of Goals (*Plano de Metas*), that industrial development finally entered the political and economic agenda of the country. Subdivided into sectors (energy, transportation, food, basic industry, and education), the plan was marked by investments in roads, iron and steel, extraction and production of oil, hydroelectric power plants, among others. Among the exponents of the plan are the creation of Petrobras and National Steel Company (*Compania Siderúrgica Nacional* – CSN), which allowed the country, in less than 10 years, to significantly increase the production of oil, pig iron, and steel (SUZIGAN, 1992, SUZIGAN and FURTADO, 2006).

As a result, there was a major push in the manufacturing industry, which contributed to a phase of vigorous economic growth that lasted until the late 1970s, accompanied by growth in the agricultural and mineral extractive sectors. From 1950 to 1980, industrial output grew at a high average annual rate (8.5%), 20% higher than that of the economy, increasing the industrial share in the gross domestic product (GDP) from 26% to 34%

(PINTO et al., 2008). This was supported by the expansion of the domestic market and utilization of remaining import substitution investment opportunities.

The world crisis that began after the second oil shock in 1979 closed markets and significantly affected the emerging Brazilian industry. In order to balance the public accounts, it was necessary to adopt policies of fiscal and monetary adjustment, which led production, employment and productivity in the country to fall. The level of investments was contracted and the effort to incorporate technical progress was reduced.

The effects of this crisis remained until the early 1990s, when the opening of national industry to international competition by the facilitation of imported products deepened the industrial crisis. As a result, according to SUZIGAN and FURTADO (2006), companies had to adapt and modernize. Most industrial segments ended up adopting survival strategies that basically followed three phases: (i) equity adjustment, comprising reduction of indebtedness and increase in revenues from investments in the financial market, (ii) redefinition of markets, through the search of sectors with high level of export coefficients, and (iii) modernization of the production process.

From 2004 on, the Brazilian industrial production began to show signs of recovery. A combination of factors favored this scenario: (i) stabilization of the economy through reduction of the inflation rate through monetary policy, (ii) reduction of the interest rate, with the consequent increase in purchasing power and recovery of the domestic market, and (iii) increase in the flow of capital and investments (increasing inflow of direct foreign investments and capital) (ALMEIDA et al., 2007).

However, in the last ten years, the competitiveness of domestic industry has fallen considerably in the global scenario, a trend evidenced by the deterioration of indicators such as the country's participation in the world exports of manufactured products, its share in the world value added of manufactured goods and the productivity of the effective work (CNI, 2015). Thus, the analysis of the economic sectors in the Brazilian GDP reveals that the industry as a whole has reduced its relative participation in economic production. The general fall recorded, however, does not mean that the industry has been producing less, but that other sectors are growing more rapidly (IEMA, 2016).

It should be noted, however, that the Brazilian industrial sector has a high degree of economic linkage with other sectors and it is highly sensitive to macroeconomic policies

(EPE, 2016; BARROS and GUILHOTO, 2014). In spite of the relative contraction of the sector, the industry maintains its relevance to the national economy: in 2015, industry accounted for 15.7% of jobs in the country and 38.1% of national exports (CNI, 2015).

There is, however, no coherent framework of measures and policies to requalify and sustain a new growth cycle in the Brazilian industrial sector (CEBDS, 2016). Such a gap becomes more relevant in the context of the consolidation of the low carbon economy, in which new competitiveness variables, such as energy and carbon intensity, can create unprecedented pressures for the sector.

In this thesis, information regarding seven Brazilian industrial subsectors (Aluminum, Cement, Lime and Glass, Chemicals, Pig Iron and Steel, and Pulp and Paper) was collected[11]. The decision to divide the industry in these seven subsectors follows the characterization used by the Ministry of Finance (MF), within the scope of the PMR project. These sectors are also the same considered in the Industry Plan (MDIC, 2013), which is the Sectorial Climate Mitigation Plan for the Consolidation of a Low Carbon Economy in the Transformation Industry. Such subsectors are those that have process emissions. Also, according to the analysis carried out in the section 2.2, these are the main industrial sectors considered in the context of designing carbon pricing policies and their instruments.

Based on the indicators calculated from the 2010 Input-Output Matrix (IBGE, 2015), this section briefly presents individual analyses of sectorial characteristics such as sales distribution, degree of concentration and structure of prices. After that, the section also provides a comparative analysis between the results of the selected industrial sectors, especially in terms of the importance of the sector, through its Gross Value of Production (GVP) and its Value Added (VA), in relation to the values of the manufacturing industry and the sectors analyzed. Then, the external vulnerability of the subsectors is evaluated by the Export Coefficient (EC). All these indicators will be detailed in the respective section.

[11] Special thanks to the following fellows from CENERGIA/COPPE/UFRJ that supported me in this sectorial analysis: Raphael Guimarães, Fernanda Guedes, Paula Guedes, and Bruno Cunha.

3.2.1. Aluminum

Regarding the distribution of sales of the sector, it is observed that most of the production of the aluminum sector serves as raw material for other segments and sectors (intermediate consumption), but is also destined for exports. In terms of production, primary aluminum production in Brazil in 2016 was 792 thousand metric tonnes, an increase of 2.7% compared to 2015. This growth pointed to a certain stabilization of the sector after the large production drops in 2014 (ABAL, 2017), which in turn can be explained by the greater competition against Chinese products and by the highwe cost of electricity, which is responsible for up to 60% of production costs. After a history of sustained production growth, Brazil has since 2009 presented successive reductions in its production of primary aluminum, after reaching its peak of 1661 thousand metric tonnes in 2008.

On the other hand, the apparent consumption of this metal showed a growth trend since 2009. While the national production of aluminum presented an average reduction of 11% per year between 2010 and 2014, apparent consumption grew 6% per year (IBGE, 2015). This consumption has been supplied by the increased use of recycled metal in the sector, as well as by imports. In this context, when compared to other countries, Brazil has a high ratio between recovered scrap and domestic consumption, reaching 38.5%, with a world average of 27.1% (DNPM, 2017).

In 2015, according to NOVELIS (2017), Brazilian capacity for aluminum production was only 935 thousand metric tonnes/year, supplied by Albras (PA) and Companhia Brasileira de Alumínio (SP). In March, Alcoa had suspended the activities of its Alumar consortium plant, cutting 74,000 metric tonnes of capacity due to lower metal prices and high production costs (NOVELIS, 2017).

Regarding the market analysis of the sector and the price formation of its products, large primary aluminum producers form the price of their alloys based on the London Metal Exchange (LME) according to the formula ‘LME + premium’, since imported aluminum incurs additional costs such as sea freight, insurance, port fees, and taxation, which become a premium for the domestic producer. In addition, aluminum recyclers follow the prices set by large companies, keeping their alloy prices below those determined. The values of the contracts are negotiated according to each company and consumer (CARDOSO, 2011).

In relation to the Brazilian aluminum market, also in 2015, the country reduced primary aluminum production and became an importer of this raw material, mainly due to the high costs of electricity, which, as previously mentioned, can account for up to 60% of production costs (ABAL, 2017). Despite this slowdown, in the year 2016 aluminum spot prices increased. At the same time, Brazilian industry reached positive numbers in that year, with a significant increase in primary metal exports. In addition, the strengthening of the US dollar against the Brazilian real provided an incentive for Brazilian producers to export. However, these factors lost strength at the end of 2016, although the perspectives of industry experts are that production will remain stable, but that exports will not grow again in the short term.

Recently, the Brazilian Aluminum Association (ABAL) and the Ministry of Development, Industry and Foreign Trade (MDIFT), through the Department of Industrial Development and Competitiveness, have established a technical cooperation agreement for the Strategic Route Project of the Brazilian Aluminum Chain 2030. The objective of the project is to conduct the sector in a process of creating knowledge regarding changes and trends in the economy, technology and society that occur at a global, national and local level, in order to anticipate the impact of these changes and trends for the aluminum chain in Brazil.

3.2.2. Cement, Lime and Glass

The majority of the production of the activities within the sector Cement, Lime and Glass serves as raw material for other segments and sectors (intermediate consumption). By conducting a market analysis and price formation of these sectors, in general, it can be said that they are intermediate segments, with a great part of their production being destined to other industrial segments. The lime and cement segments have a strong relationship with the civil construction industry, while the glass sector is dependent on purchases from the automobile industry. In addition, as a whole, the segment cement, lime and glass has low profit margin, which could hinder the absorption of a possible cost of carbon (RATHMANN, 2013).

The Brazilian cement industry operates with low profit margins, having great difficulty in passing on costs. In addition, the degree of market concentration of the sector is not very high, making the spread of new costs to the consumer more dispersed, with the marginal cost of all producers increasing. Despite the fact that there is no international competition, the effects of low margins combined with the low concentration of companies result in major barriers in the sector for the incorporation of new production costs, being therefore exposed to the effect of possible carbon pricing.

In the lime sector, price formation can vary widely, depending on its application. It can be considered a sector that is not susceptible to external competition, since its apparent consumption accompanies the level of production, that is, lime produced in Brazil is almost completely absorbed by the domestic market, with no need for imports. Another characteristic of this sector is its heterogeneity of producing companies, with highly different behaviors. According to JMENDO (2009), large companies, often multinationals with large working capital, are more able to absorb market oscillations and invest in new technologies and opportunities, while small firms rely heavily on government intervention to ensure their competitiveness.

In the glass sector, the oligopoly characteristic has been maintained and almost half of the production of flat glass and packaging belongs to one company, Saint Gobain. The glass market has had a favorable trade balance in the past, however, in recent years it has lost international competitiveness due to China's strong entry into this market and also due to high natural gas prices in Brazil. The glass segment in the country uses mainly natural gas (95%) in its furnaces (CNQ, 2015). Thus, prices have a great impact on the costs of the sector. It is estimated that the expenses with natural gas and electric energy correspond to about 25% of the final cost of production, and can reach 35% (CNQ, 2015).

3.2.3. Chemicals

Regarding the distribution of sales of the sector, it is observed that most of the production of the Chemical sector serves as raw material for other segments and sectors (intermediate consumption), but it is also destined to household consumption and exports. The chemical industry has a different characteristic from the other industrial activities, since it has a great interdependence in terms of raw materials (ABIQUIM, 2010). In addition, the demand for basic chemical inputs is highly dependent on several generations of the industry's own intermediate products that are required for the production of its final products. These, in turn, depend on industrial consumption and final consumption, and are therefore highly elastic to GDP growth (KUPFER et al., 2006).

Another relevant feature of this industry is its heterogeneity, besides the fact that the chemical industry includes numerous products inserted in different categories (ABIQUIM, 2016). Thus, assessing the market and the impact of possible carbon pricing in each of the areas of this industry would require a level of analysis that calls for detailed information on each of the subsectors and products. Each product and each segment has its particularity concerning market and national or international competitiveness. Thus, in this context, some general aspects of the competitiveness of this industrial sector will be presented, focusing on some segments with relevant peculiarities.

One of the categories included in the chemical sector is the manufacture of pharmaceuticals and pharmachemical products. Despite being a market for small consumers, these sectors has been suffering pressure coming from large institutions for a flexibilization of the prices given a certain purchasing power they have due to sale to large corporations associated with large volumes. Examples of such institutions are the State, hospitals and clinics. For the government, it is interesting that the population has access to a lower cost medication, which ultimately deprives public health spending. Also, health plans may be important in determining competitive prices, as they are interested in lowering drug prices in order to reduce coverage costs. These factors also weaken the pricing power of pharmaceutical oligopolies (MOREIRA and VARGAS, 2009).

In the case of the petrochemical industry (another category within the chemical sector), its competitiveness can be related to two main exogenous factors: the availability and price of raw materials and the high fixed cost of investment (CNI, 2010). As a highly capital intensive industry, petrochemicals have been configured over the years around vertical and horizontal integration, which guarantees, among other advantages, the possibility of operating with monopoly characteristics and economies of scope, with a large presence of companies. Its dynamics are related to international price cycles, which in turn are determined by the prices of raw materials and the balance between installed capacity and demand (BAIN and COMPANY, 2014).

The market for basic and second-generation petrochemicals is highly dependent on oil prices. Resins are commodities sold in the global market and their prices vary according to global macroeconomic factors. The profitability of the companies manufacturing these raw materials is established according to the spread, in which the cost of the raw material for production depends largely on the price of naphtha, an input price based on the price of crude oil. Thus, this market oscillates between moments with very narrow margin and high margin, due to the oil prices (BRASKEM, 2016).

The apparent national consumption of the chemical industry has been declining in recent years, and Brazil has become increasingly dependent on the international market, either for the sale of products that are not being absorbed locally, or for import, making it vulnerable to the global macroeconomic situation (BRASKEM, 2016). In the international scenario, the price of oil, and consequently of petrochemical naphtha and natural gas, is reflected in the international price of several chemical products, interconnected with each other from basic raw materials linked to petroleum (CNI, 2010).

The fertilizer segment, in addition to variations in the price of natural gas, is related to variations in the price and demand of international agricultural commodities. In the case of nitrogen fertilizers, the main raw material used is natural gas. About half of the national consumption is imported, and varies according to a basket of petroleum products. In addition, natural gas prices practiced in Brazil are significantly higher than those practiced in the USA (KUPFER et al., 2006).

It is also worth noting that exchange rate variations also have an impact on the competitiveness of the national chemical industry, which is dependent on imports of basic products, and its investments are based on foreign currencies. Thus, the turnover of the chemical industry, which presents steady growth in the Brazilian currency, suffers strong oscillations when considering its turnover in dollars.

3.2.4. Pig Iron and Steel

The production of the Pig Iron and Steel sector presents important commodities destined to the foreign market, but also serves as raw material for other segments and national sectors (intermediate consumption). In terms of production, the Brazilian steel industry is operating with large idle capacity, directly associated with the country's economic situation. Since 2007, the Brazilian steel industry does not operate with more than 85%

of its capacity, ranging from an utilization of 87% in 2007, to an average utilization rate of 70% in 2014 (IAB, 2013, 2017).

In addition, the industrial park has relatively new facilities (between 1990 and 2003, steel production in the country increased by 50%). This characteristic combined with the current high idleness points to a delay in the resumption of investments in installed capacity, even in a moment of resumption of economic growth in the country.

By carrying out a market analysis of the sector, and its price formation, its high sensitivity to external competition is perceptible. Thus, if the values of the national products go up, they would be replaced by imports. In recent years, increased steel imports combined with reduced domestic demand have had a severe impact, greatly increasing the country's idle capacity. On the other hand, the good quality of Brazilian iron ore can be considered as a competitive advantage of the country in a market in which international competition is extremely relevant.

Meanwhile, the country faces competitive asymmetries in the international market, resulting in difficulties for the domestic industry to compete with imported steel. According to the Brazil Steel Institute (IAB, 2017), the export would be an option to improve the degree of utilization of installed capacity. Today, with an approximate 60% idleness due to the Brazilian domestic market, the steel sector is living with international capacity surpluses that exceed 700 million metric tonnes, resulting in unfair trade practices and depreciated prices.

3.2.5. Pulp and Paper

For the Pulp and Paper sector, most of the products serve as raw material for other segments and sectors (intermediate consumption), and are destined for exports. Regarding the sector's price structure, Brazil is currently one of the world's leading producers of pulp, ranking second in exported volume of pulp and the first place in the export of bleached sulphate/kraft pulp (BRACELPA, 2015; BNDES, 2010). Its great differential consists in the use of eucalyptus in its short fiber production, which has a shorter time for cutting (seven years) and high productivity (44 m^3/ha/year). With regard to the production costs of hardwood pulp in Brazil, these are among the lowest in the world. In addition, the cost structure is made up of the costs of wood, chemicals, energy, labor, maintenance, freight and others.

According to MONTEBELLO and BACHA (2013), Brazil is a price taker in the international market, due to the small size of its production and exports in relation to the volume sold worldwide. According to BNDES (2010), prices in the international pulp market are cyclical in nature, being sensitive to changes in industry capacity, inventories of producers, the exchange rate, production and freight costs, and, above all, to the oscillations of world economic activity. Another aspect that stands out is the fact that prices for both long-fiber and short-fiber pulp vary at about the same rate, reflecting the fine-tuning of the two products in the market and reduces arbitrage opportunities. Thus, companies with higher (lower) production costs work with lower (higher) margins, and are the first (last) to suffer downtime in downward cycles of commodity prices.

In relation to the price of paper, these are determined by the supply and demand conditions in the regional markets, although with a more stable behavior than pulp prices. In addition, they suffer fluctuations as a direct result of several factors, including fluctuations in pulp prices and specific market characteristics.

3.2.6. Comparative Analysis

Considering the main purpose of this thesis, the comparative analysis focus on some specific economic indicators. The general economic characterization of the sector begins with the analysis of the importance of the sector, through its Gross Value of Production (GVP)[12] and its Value Added (VA)[13], in relation to the values of the manufacturing industry and the sectors analyzed. The methodological detail is found in Annex A. After that, the external vulnerability of the subsectors is evaluated by the Export Coefficient (EC)[14] and its methodological detail is also found in Annex A.

Figure 7 shows that in the 2010 the Chemical subsector had the highest participation (10.2%) in relation to the total VBP of the manufacturing industry, followed by Iron and

[12] It corresponds to the sum of all goods and services produced, both final products and inputs used in production.
[13] It corresponds to the difference between the GVP and the intermediate consumption.
[14] It corresponds to the percentage of production that is exported, so the higher the EC, the greater the importance of external sales to the industry.

Steel (7.4%) and Cement, Lime and Glass (4%). These three sectors accounted for about 20% of the VBP of the manufacturing industry, totaling R$ 430 billion.

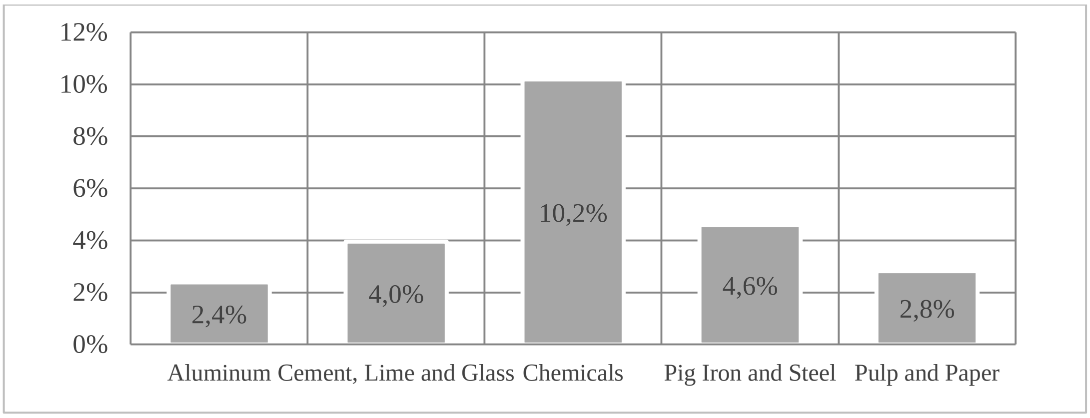


Figure 7 – Subsectors' GVP participation in the manufacturing industry, 2010

Source: Own elaboration based on IBGE (2015)

In Figure 8, the participation of the VA of the selected sectors in relation to the total VA of the manufacturing industry is depicted. In this case, the Chemical sector stands out with 10.1%.

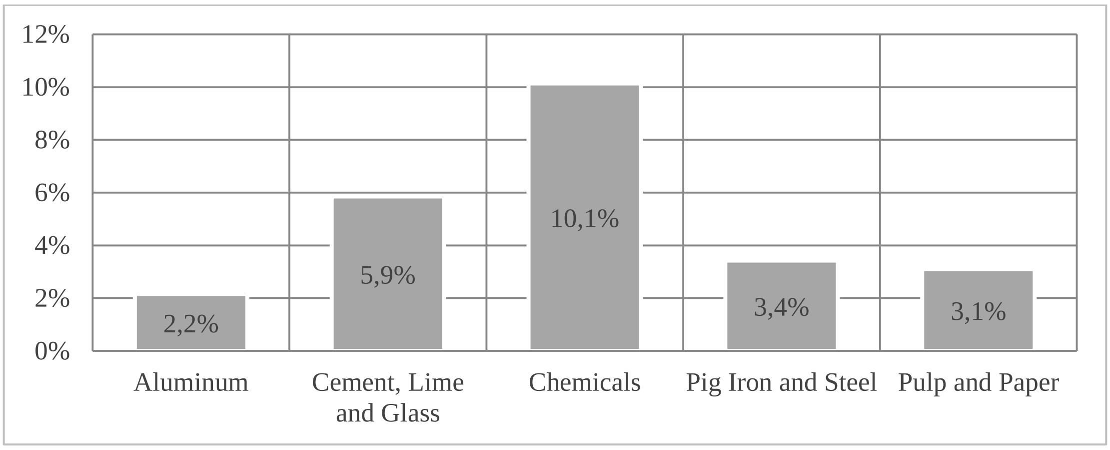


Figure 8 – Subsectors' VA participation in the manufacturing industry, 2010

Source: Own elaboration based on IBGE (2015)

With regard to external vulnerability and with the purpose of verifying possible impacts on sector competitiveness, it is possible to observe, in Figure 9, the participation of exports in the production of the activities of the selected sectors. According to the concept of the coefficient of exports in the production structure, in 2010, iron ore extraction, including processing and agglomeration (Iron and Steel), was the most vulnerable segment among the sectors selected, with 89% of exports per unit of production. Then, we have the extraction of non-ferrous metal minerals, including beneficiation (Aluminum), which represented the second most vulnerable segment in relation to the selected sectors of the study, with 34% of exports per unit of production. Still within the Aluminum sector, non-ferrous metal metallurgy and metal casting appears as the third most vulnerable activity with 31%. Extraction of mineral coal and non-metallic minerals and manufacture of non-metallic mineral products (belonging to the subsector Cement, Lime and Glass) showed the lowest export coefficients, both with 6% of exports per unit of production, and therefore, less vulnerable than the others.

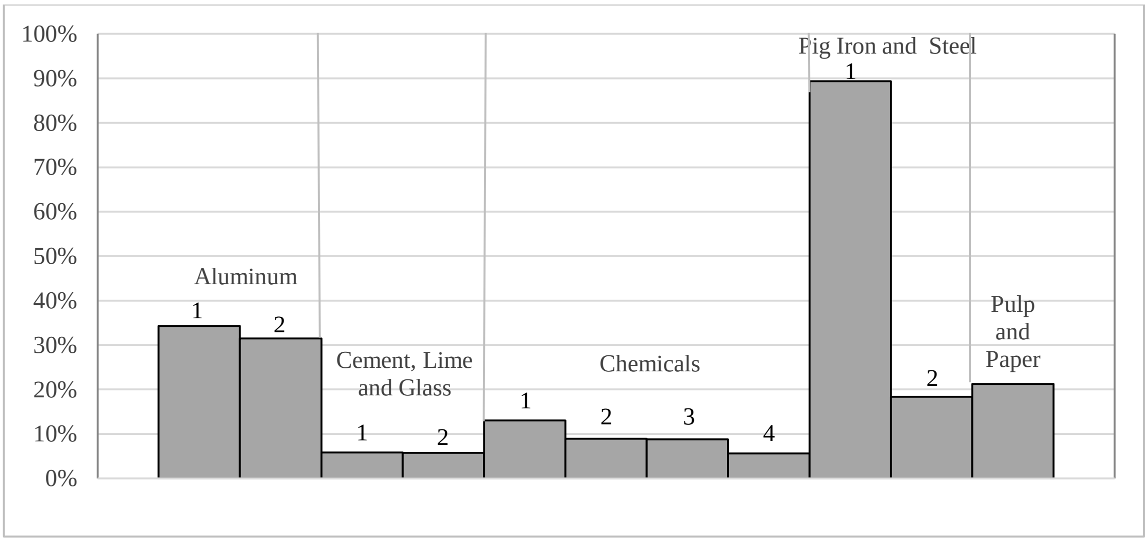


Figure 9 – Subsectors' export participation in the activity production of the selected subsectors, 2010

Source: Own elaboration based on IBGE (2015)

Note:
Aluminum 1: Extraction of non-ferrous metal ores, including improvements; Aluminum 2: Metallurgy of non-ferrous metals and metal smelting; Cement, Lime and Glass 1: Extraction of coal and non-metallic minerals; Cement, Lime and Glass 2: Manufacture of non-metallic mineral products; Chemicals 1: Manufacture of other organic and inorganic chemicals, resins and elastomers; Chemicals 2: Manufacture of pesticides, disinfectants, paints and various chemicals; Chemicals 3: Manufacture of cleaning products, cosmetics/perfumery and personal hygiene; Chemicals 4: Manufacture of pharmaceutical and pharmachemical products; Pig Iron and Steel 1: Extraction of iron ore, including processing and improvements; Pig Iron and Steel 2: Production of pig iron/ferroalloys, steel industry, and seamless steel pipes; Pulp and Paper: Manufacture of pulp, paper and paper products.

Table 7 summarizes these indiactors per subsector in US$ millions.

Table 7 – Economic characterization indicators of the analyzed industries (US$ millions, 2010)

Source: Own elaboration based on IBGE (2015)

Subsector	VA (US$ millions)	VBP (US$ millions)	Exports (US$ millions)	Imports (US$ millions)
Aluminum	5,010	22,359	7,170	3,715
Cement, Lime and Glass	10,487	30,092	1,731	1,679
Chemicals	7,196	26,387	9,570	32,225
Pig Iron and Steel	23,519	95,443	7,893	5,277
Pulp and Paper	7,945	42,952	5,608	1,751

3.3. Sectorial Emissions Profile

Considering sectorial emissions, if in recent decades the Brazilian industry has lost its relative position in the national economy, its GHG emissions gained importance as deforestation decreased (participation in net CO_2 emissions from land use, land use change, and forestry reduced from 83.4% in 2005 to 42% in 2010 – MCTI, 2015). In 1990, the industrial sector accounted for 8.5% of the total GHG emissions (including fuel combustion and industrial processes), while in 2010 it reached 22.6% MCTI (2015). Figure 10 presents the total Brazilian GHG emissions in 1990, 1995, 2000, 2005, 2010, and 2014 (the latest available year by the Ministry of Science, Technology and Innovation (MCTI, 2016). The increase in both energy and industrial process emissions reflects the growth of the Brazilian economy (activity effect) throughout the period.

Contrary to that evolution, there was a reduction in emissions from land use, land-use change, and forestry (LULUCF) after 2005, due to the decrease in deforestation (SANTOS et al., 2018). However, it remains to be seen whether this trend will reverse in the next decade due to governmental policies favoring land grabbing in Brazil implemented over the last three years (ROCHEDO et al., 2018). This deforestation emission reversal trend can certainly pose new challenges to Brazil's industrial sector to mitigate GHG emissions (ROCHEDO et al., 2018).

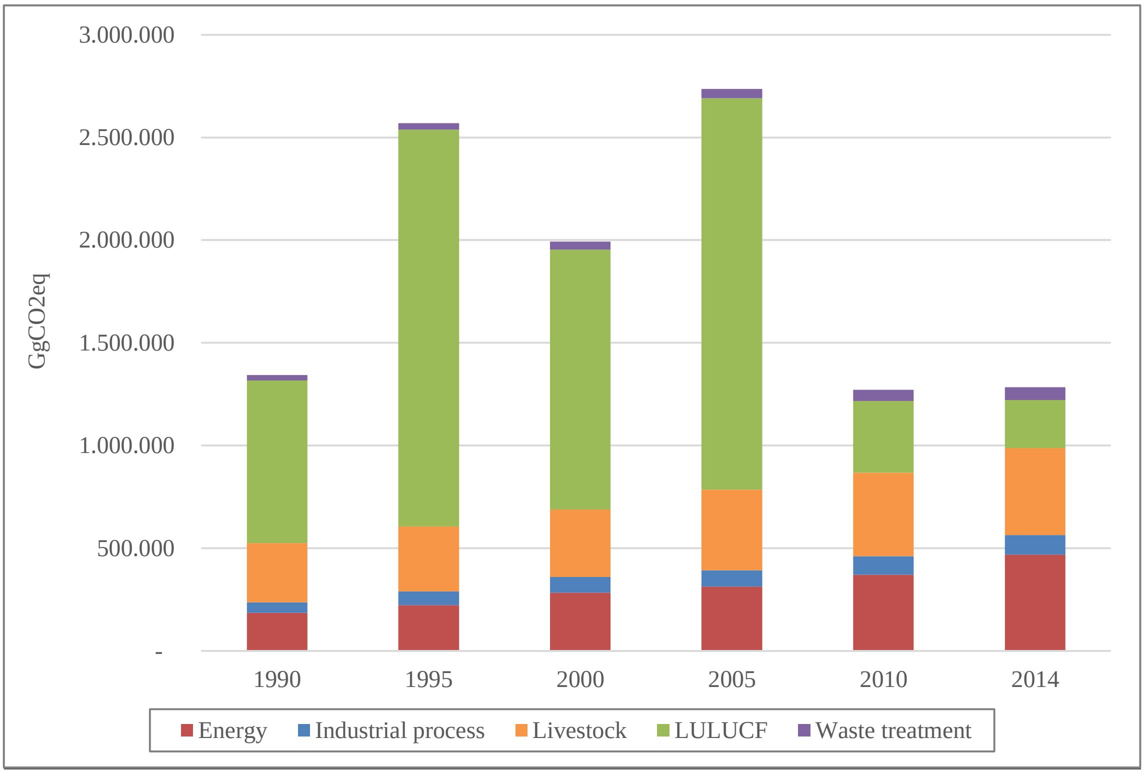


Figure 10 – Brazilian GHG emissions by origin in 1990, 1995, 2000, 2010, and 2014 (values in Gg CO_2eq)

Source: Own elaboration based on MCTI (2016)

Figure 11 presents the total industrial GHG emissions by origin (energy or process) in 2005, 2010, and 2014. There was an 11% increase in total emissions from 2005 to 2010 (14% from fuel combustion – energy - emissions and 9% from industrial process emissions), while the comparison between 2014 and 2005 reveals a 21% increase in total GHG emissions (24% from energy emissions and 19% from process emissions).

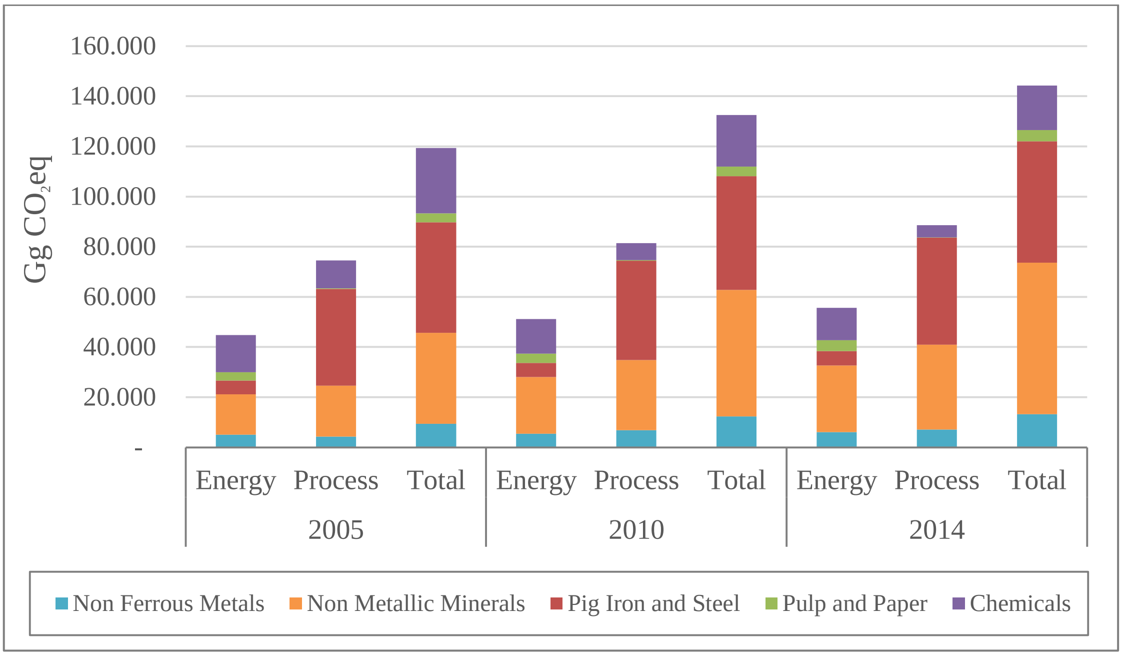


Figure 11 – Brazilian GHG emissions by origin in 2005, 2010, and 2014 (values in Gg CO_2eq)

Source: Own elaboration based on MCTI (2016)

There should be noted that there are several opportunities to reduce GHG emissions in Brazil (MCTI, 2016; WORLD BANK, 2010). More specifically, in the industrial sector, incentives for efficiency and processes innovations (R&D), new financing instruments, implementing specific regulatory instruments – such as a carbon pricing – and technological standards are key drivers for developing a low carbon industrial sector in Brazil (CEBDS, 2016, 2017). Nevertheless, challenges also exist in this sector, such as the high abatement costs for some mitigation options, and the incipient stage of some technologies (PINTO et al., 2018; HENRIQUES et al., 2010), the need for adaptability of those technologies to Brazilian plants, and the difficulty to obtain cheap loans and financing (CEBDS, 2017).

From the context about the industry emissions profile, it is important to understand and analyze the history of emissions from the sector, in a subsectorial level, through national inventories. To do so, emissions data from the same seven major Brazilian industrial subsectors assessed in the economic characterization (Aluminum, Cement, Lime, and Glass, Chemicals, Pig Iron and Steel, and Pulp and Paper) was collected and they are briefly presented and analyzed in the following subsections. After that, a subsectorial comparative analysis is carried out. Methodological details are presented in Annex B.

3.3.1. Aluminum

The aluminum industry in 2010 reached the total CO_2 emissions 2.544 Gg, caused by the manufacturing process (Figure 12).

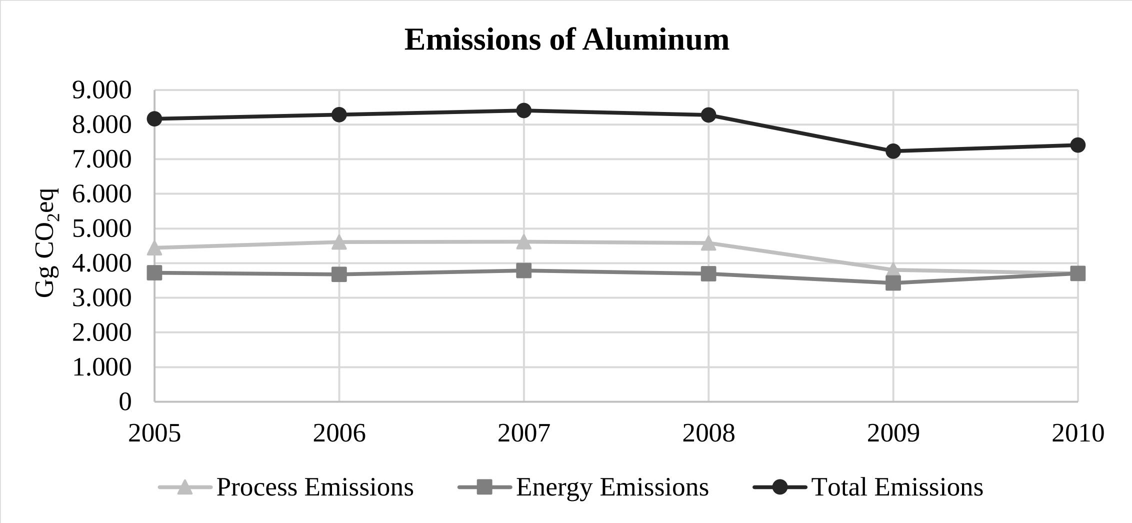


Figure 12 – GHG emissions from the Aluminum subsector ($GgCO_2eq$)

Source: MCTI (2015)

3.3.2. Cement, Lime and Glass

Cement production is an energy-intensive process, resulting in carbon dioxide emissions not only from fuel consumption, but also from the calcination of limestone. A comparison between the process emissions and the energy emissions of the cement subsector (Figure 13) shows that there is a tendency for emissions to grow in recent years, so the application of energy efficiency measures is highly significant in order to reduce these emissions as well as their impact on the environment.

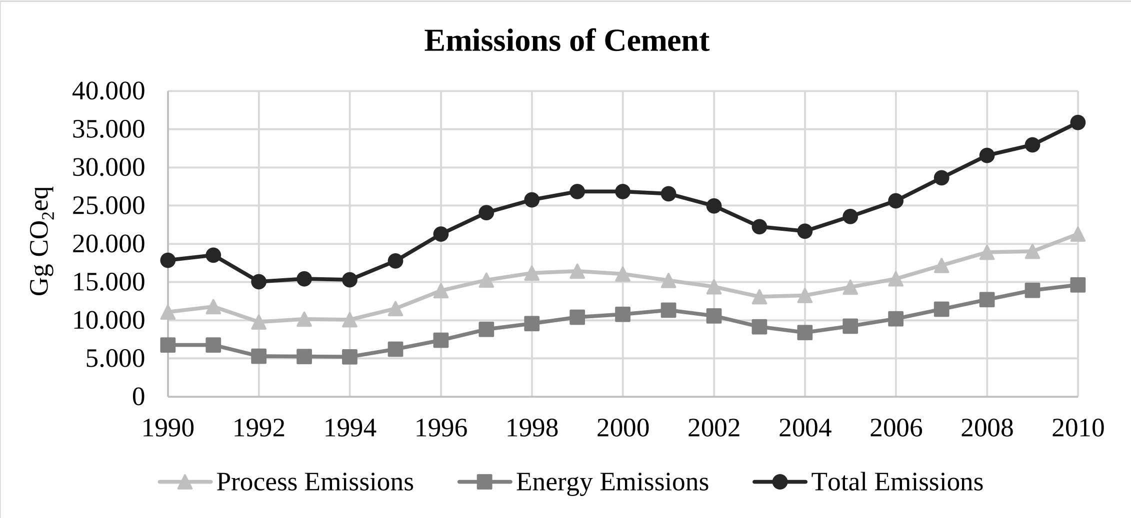


Figure 13 – GHG emissions from Cement subsector ($GgCO_2eq$)

Source: MCTI (2015)

In general, the cement industrial park in Brazil presents high-energy efficiency values when compared to the world average, both in terms of electric and thermal energy consumption (CNI, 2010). This is due to the fact that the Brazilian cement park is new, not presenting much lag in relation to the most advanced technologies.

In relation to the production of lime, many modifications were introduced in the processing of this product, seeking to improve its reactivity and reduce the specific energy consumption (kcal / t of lime for the product manufactured) (CNI, 2010). According to Figure 14 below, it is possible to see that the process emissions are more relevant in relation to the total emissions of the sector.

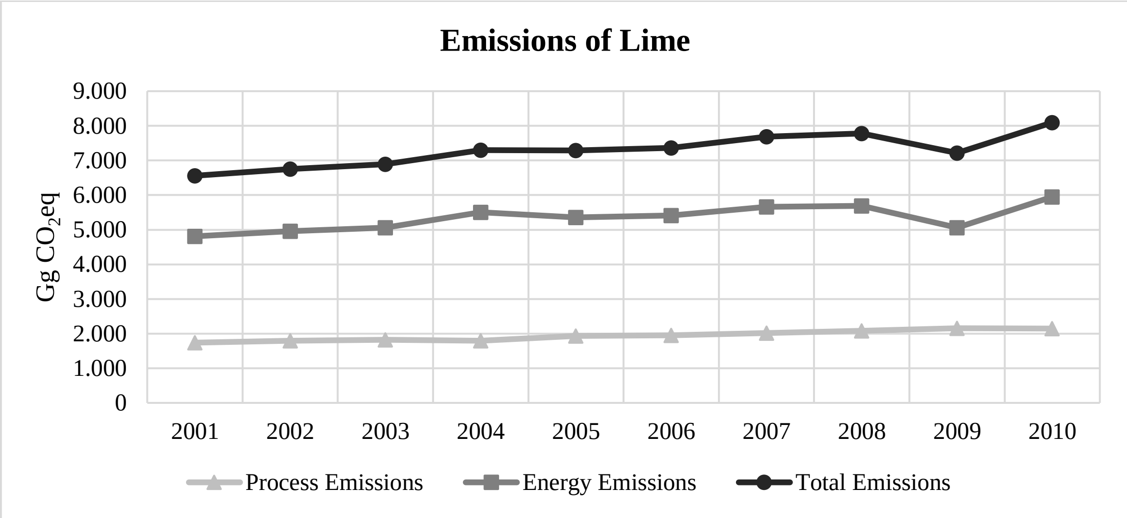


Figure 14 – GHG emissions from Lime subsector (GgCO_2eq)

Source: Own elaboration by the author based on CNI (2010)

Regarding the production of glass, according to the Third National Communication of Brazil to the United Nations Framework Convention on Climate Change (MCTI, 2015) emissions in glass production process reached only 114 GgCO_2 in 2010. Energy emissions could not be obtained directly from the TCN nor indirectly through data from the National Energy Balance, where the glass production sector is not detailed. Therefore, a similar methodology used to the lime industry was applied: knowing the glass production of subsequent years (2007 to 2010) it was possible to extrapolate the consumption of energy by making use of the historical database. Finally, making use of each energy emission factors was possible to determine the energy emissions profile in the glass industry (Figure 15).

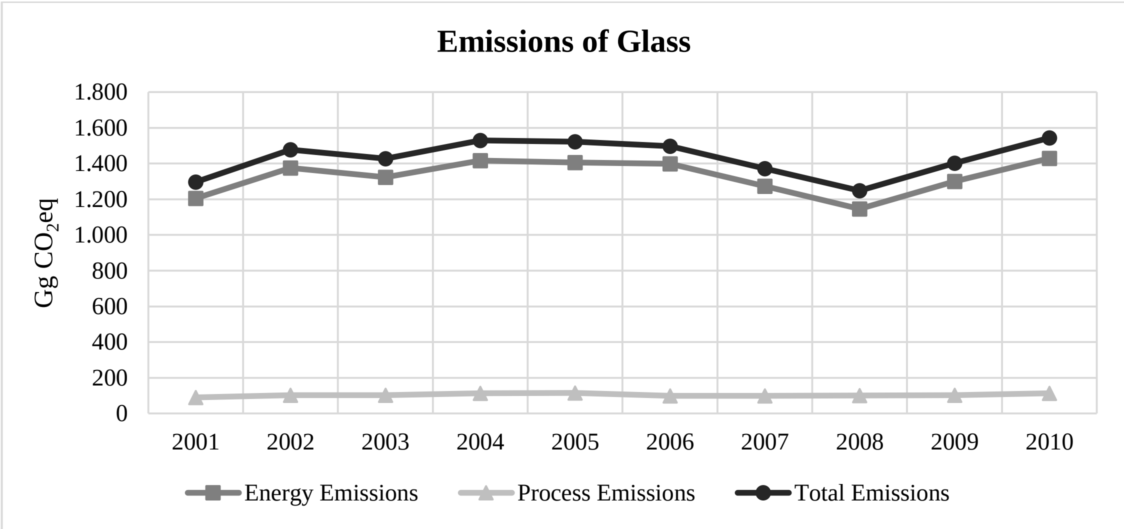


Figure 15 – GHG emissions from the Glass subsector (GgCO_2eq)

Source: Own elaboration by the author based on CNI (2010)

3.3.3. Chemicals

Due to the fact that the chemicals sector is an intensive energy user and it has an important role in the economy by providing inputs to many other industries, the chemical industry is a targeted investment sector in terms of R&D of new technologies around the world. In fact, according to IEA (2014), the chemical and petrochemical sector accounts for about 10% of world final energy demand and for 7% of global emissions of GHG.

The highest energy consumption and emission intensity is concentrated in the production of eighteen products[15] that account for 80% of the energy demand of the chemical industry and 75% of the emissions (IEA, 2014). Figure 16 shows the relationship between energy emissions and process emissions, evidencing the discrepancy between these values and that the composition of the sector is mainly due to the emissions of energy.

[15] Acrylonitrile, ammonia, benzene, caprolactam, cumene, ethylene, ethylene glycol, ethylene oxide, HDPE, LDPE, LLDPE, methanol, xylenes, phenols, PP, propylene, propylene oxide, p-xylene, styrene, terephthalic acid, toluene and vinylidene chloride.

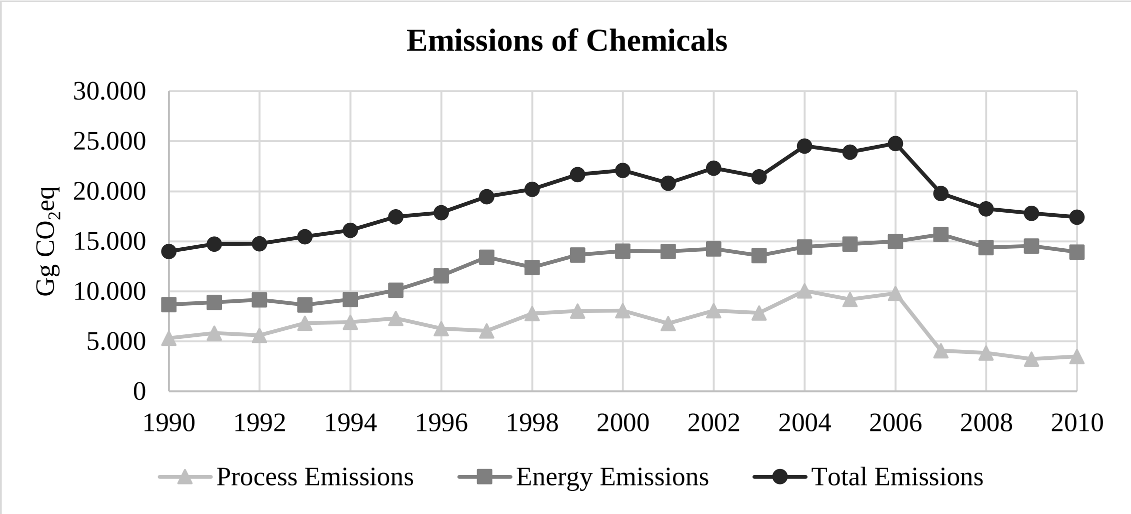


Figure 16 – GHG emissions of the Chemical subsector ($GgCO_{2eq}$)

Source: MCTI (2015)

3.3.4. Pig Iron and Steel

The Pig Iron and Steel industry accounts for 38% of total emissions of the sectors studied (MCTI, 2015). This subsector is also responsible for the higher process emissions indices of the subsectors analyzed reaching the value 38.360 $GgCO_2$ in 2010 (Figure 17).

As shown in the Figure 17, this sector has a relatively low energy emissions if compared to the process emissions. Pig iron and steel subsector reached the energy emissions of 5,557 $GgCO_2$ in 2010.

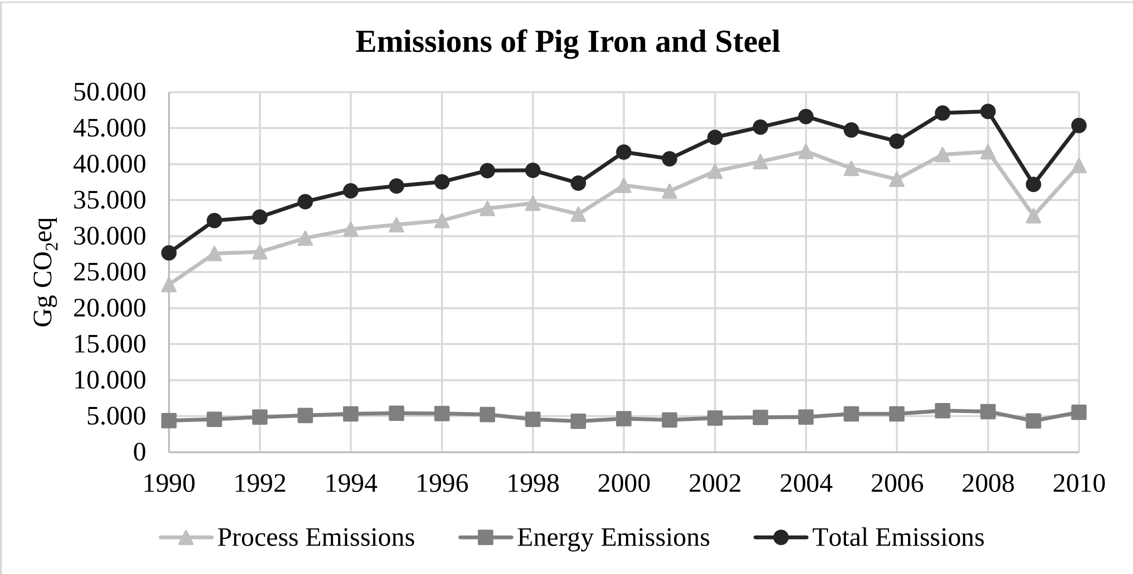


Figure 17 – GHG emissions from the Pig Iron and Steel subsector ($GgCO_2eq$)

Source: Own elaboration based on CNI (2010)

3.3.5. Pulp and Paper

According to the National Energy Balance 2013 (EPE, 2014), the Pulp and Paper industry was the third largest energy consumer in the Brazilian industrial sector, accounting for approximately 14% of total industry consumption. Also according to EPE (2014), the sector significantly increased its energy use in the last ten years, presenting in 2013 a consumption of approximately 10.5 million toe, which is an amount 45% higher than the published value for the year 2004.

The main energy sources used by the industry were liquor, corresponding to 47.1% of the total energy used then electricity with 15.9% and 15.3% fired with natural gas at 7.6%. Thus, it is observed that although the sector is intensive in energy use, much of its generation comes from renewable sources.

In addition, with respect to the process GHG emissions, they are low compared to other industries. The production of chemical pulp, in particular, performed primarily by the kraft process is indirect GHG emitting since during the preparation of pulp by the kraft process, chemical reactions are emission sources of CO, NOx and NMVOC. With regard to energy emissions, these are considerably more significant. Figure 18 shows the process, energy and total emissions of this sector.

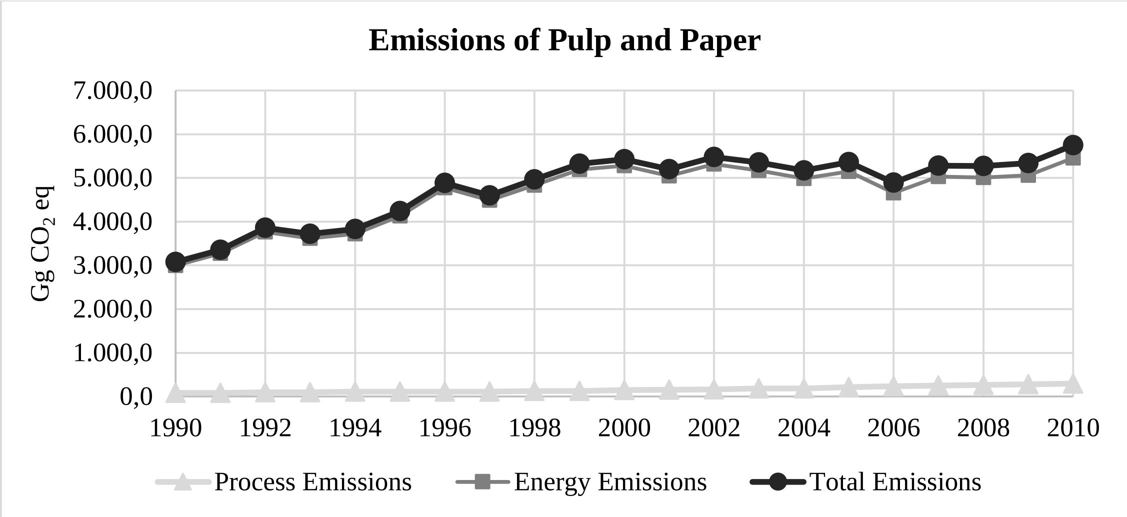


Figure 18 – GHG emissions of the Pulp and Paper subsectors ($GgCO_2eq$)

Source: MCTI (2015)

3.3.6. Comparative Analysis

The previous section presented information on the emissions profile of seven Brazilian industrial subsectors (Aluminum, Cement, Lime and Glass, Chemicals, Pig Iron and Steel, and Pulp and Paper). The emissions were separated into "Process Emissions" and "Energy Emissions" according to the classification of the *Third Brazilian Inventory* of Anthropogenic Emissions and Removals of Greenhouse Gases (MCTI, 2015).

The compilation of the results obtained is shown in Table 8, indicating a total of 121,493 $GgCO_2$ equivalent in 2010, being 61.4% of the value associated with industrial process emissions, while the rest (38.6%) related to the consumption of energy.

Table 8 – Emissions profile of the analyzed industries (Gg CO_2eq, 2010)

Source: Own elaboration based on MCTI (2015)

Subsector	Energy Emissions	Process Emissions	Total Emissions	Relative Percentage (%)
Aluminum	3,702	3,708	7,410	6.1%
Cement	14,619	21,288	35,907	29.6%
Chemicals	13,949	3,488	17,438	14.4%
Glass	1,429	114	1,543	1.3%
Pig Iron and Steel	5,557	39,794	45,351	37.3%
Lime	2,148	5,950	8,098	6.7%
Pulp and Paper	5,455	292	5,747	4.7%
Total	46,859	74,634	121,493	100.0%

Figure 19 shows the impact of each subsector analyzed in the total percentage of CO_2 equivalent emissions, with the Pig Iron and Steel sectors being the most significant, accounting for 37% of emissions, followed by the Cement and Chemical sectors, with about 30% and 14% respectively.

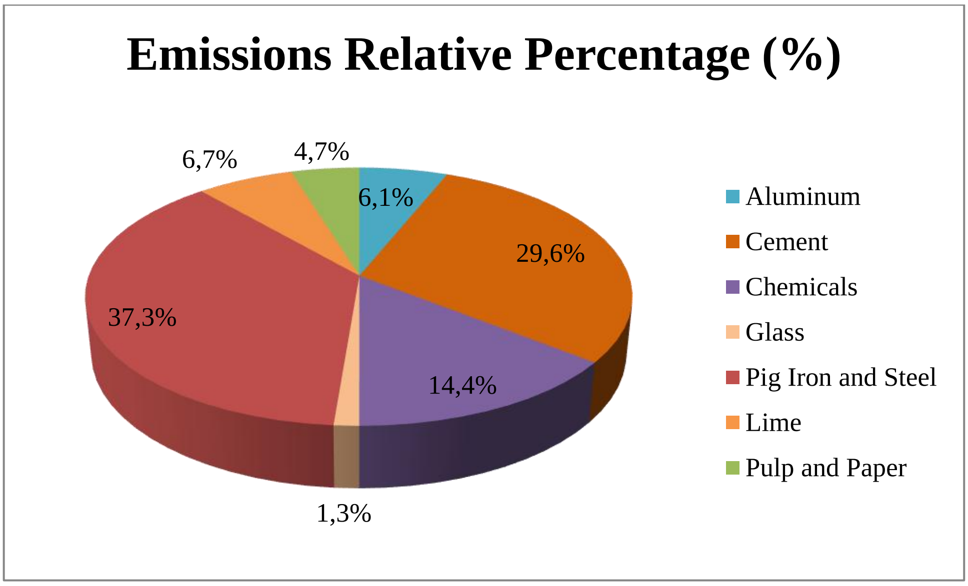


Figure 19 – Emissions profile by subsectors (%)

Source: Own elaboration based on MCTI (2015)

Figure 20 shows the subsectorial relative percentage disaggregation by energy and process emissions. The Cement and Chemical sectors presented the two largest volumes of energy emissions, with around 30%, while the Pig Iron and Steel sector leads the process emissions with a total of 53%.

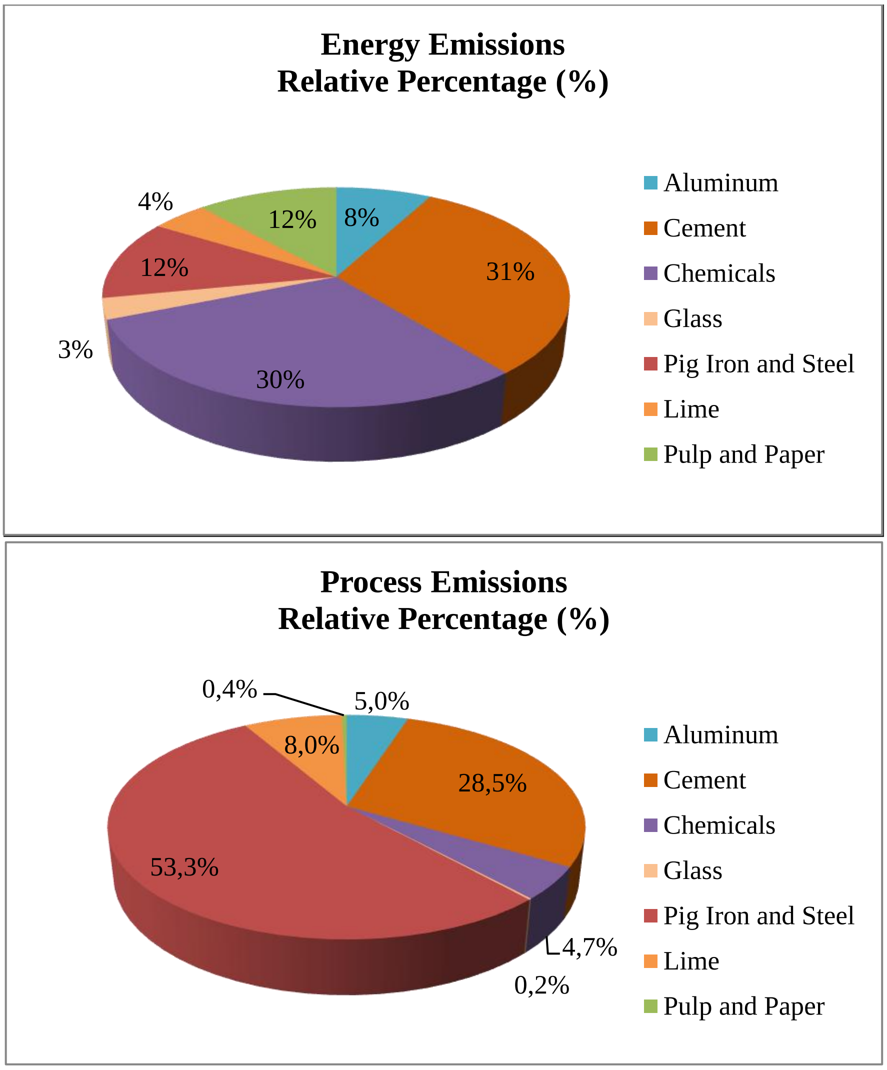


Figure 20 – Breakdown of Energy Emissions and Industry Processes

Source: Own elaboration based on MCTI (2015)

3.4. Mapping of Sectorial Policies

The main objective of this thesis is to analyze how carbon pricing policy impacts the industrial sector and its subsectors. In this context, it is important to understand how such impacts interact with other existing policies, for example, industrial, commercial and tax policies. Taking the tax policy as an example, it is important to assess the instruments that already exist in the tax legislation by redirecting its use in order to give the correct stimuli to a production with low carbon emission. At the same time, it is urgent to eliminate the subsidies paid to activities that are clearly intensive in GHG emissions.

The analysis of these impacts and trade-offs of policies, and their respective instruments, needs to be evaluated in more detail, aiming not only to reduce GHG emissions in the sector, but also to understand its impacts on the competitiveness. It is also worth noting that the implementation of carbon pricing policies in each of the industry subsectors can generate impacts in other economic sectors indirectly, given the intersectorial connections. In this way, the scope of sectors can be expanded as a result of possible indirect interactions, as will be shown in Annex C.

Having said that, in order to analyze specifically the Brazilian industrial sector, the analytical framework of this thesis is organized into five policy groups, which will be briefly analyzed from their respective instruments: (i) sectorial stimulus policies, (ii) rational use of resources policies, (iii) tax policies, (iv) climate policies, and (v) environmental policies with emphasis on atmospheric emission control, as detailed below. This analytical framework was developed in the context of the Component 1 of the Brazilian PMR Project and in this thesis a short presentation and analysis will be carried out considering the five policy groups.

3.4.1. Sectorial Stimulus Policies

The sectorial stimulus policies aim to stimulate the growth and development of industrial subsectors, with direct effects on the subsectors of Brazilian industry. Among them, we can highlight the policies and instruments already in place in Brazil that mainly aim to promote a specific subsector, for example, through policies to support R,D&I and industry financing, government procurement, local content, among others. It should be emphasized that the sectorial stimulus discussed here does not aim at environmental goals and/or rational use of resources, but rather goals per se to stimulate a given sector, which are justified in aspects such as international trade, income and employment generation, increase industrial competitiveness, local development, etc.

In terms of policy instruments, R,D&I activities aim to extend knowledge applied to new products or processes, as well as to improve existing products and processes. Usually, such activities are carried out by research centers, companies, universities or government agencies. Policies to stimulate R,D&I have direct and indirect intersectorial effects - in practice, bringing them closer to structuring industrial policies. In recent years, this policy has been primarily implemented with a focus on stimulating and investing basic infrastructure of research, technology and innovation, as well as indirect support, through fiscal incentives (ALVARENGA et al., 2012), with emphasis on the participation of the Financier of Studies and Projects (FINEP) and the Brazilian Development Bank (BNDES).

Another instrument is public investments, for example, through government procurement. Studies by IPEA (2010b) show that public investments have been extensively used by governments in several countries - with more intense use by developed nations - for the implementation of public policies. In general, these are directed to at least one of the following objectives: incentive to industry; increased investment in R&D, combined with stimulation of innovation; and improvement in the provision of public services. In Brazil, in particular, the current bidding process for public procurement is a policy that seeks to reflect and even suggest changes in the state's performance in the promotion of sectorial incentives, through public policies.

Lastly, the Local Content (LC) regulation instrument is highlighted, which is part of a federal government policy to increase the participation of the national industry in the supply of goods and services, generating employment and income for the country stands out. According to ALMEIDA (2015), LC's policies are developed with the purpose of achieving specific economic and social objectives, mainly through the realization of national investments in a given good or service, corresponding to the share of national industry participation in its production. It is, therefore, an industrial policy. In Brazil, the policy is part, in particular, of the oil and gas, and wind energy sectors. Thus, when an oil platform or wind turbines, for example, have a high index of local content, it means that the goods and services used in their construction are, to a large extent, of national origin, not imported. Thus, the entire supply chain of these sectors is developed.

3.4.2. Rational Use of Resources Policies

The rational use of resources policies aims to stimulate the rational use of resources, such as energy, water and solid waste. Their instruments include the creation of government programs, whose initiatives seek to promote norms and standards of energy efficiency and have been developed since the early 1980s. Thus, discussions at the National Institute of Metrology, Quality and Technology (INMETRO), for example, lead to the creation of the Brazilian Labeling Program (PBE), in 1984, the National Electricity Conservation Program (Procel), in 1985, which is managed by Eletrobras, the National Program for the Rationalization of the Use of Oil and Natural Gas Derivatives (Conpet), under the responsibility of Petrobras in 1991, and the National Institute of Energy Efficiency (INEE) in 1992 (LEITE, 2013).

Through the Interministerial Ordinance Nº. 1877 of the MME and the MDIC, the National Electricity Conservation Program (Procel) was instituted, with the objective of promoting the rationalization of electricity production and consumption in order to eliminate waste and reduce costs and sectorial investments, indirectly contributing to the reduction of environmental impacts resulting from avoided GHG emissions. The National Program for the Rationalization of the Use of Oil and Natural Gas Derivatives (Conpet) was instituted through a Presidential Decree with the objective of promoting the development of an anti-waste culture in the use of non-renewable natural resources in several sectors of Brazil, with emphasis on residences, transports, and industries. Contrary to Procel, Conpet does not have an action that directly refers to the industrial sector, but affects this sector by establishing an equipment-labeling program, both from the perspective of the producer of these equipment, and from the perspective of the industrial facility that will adopt certified equipment.

In the context of the rational use of resources policy, it is notable the role of ISO 14040, which deals with the Life Cycle Analysis of Products, as well as Law Nº. 12305/10 of August 2, 2010 (BRASIL, 2010a), also known as the National Solid Waste Policy (PNRS), whose main objective is to create political mechanisms to curb the inadequate management of solid waste. Some instruments were instituted by the PNRS, such as reverse logistics and recycling, which have a direct impact on the rational use of resources. Also within the scope of government programs, the National Water Resources Policy (PNRH), which exists since 1997, is a guideline for the country's water management and seeks to develop public policies that promote the improvement of water quality and quantity (BRASIL, 1997).

Lastly, in terms of instruments for this policy, we can also highlight investments in R&D in the area of energy efficiency, in particular by concessionaires, licensees and authorized companies in the energy sector, as well as a series of financing from BNDES to promote the rational use of resources, among which BNDES Eficiência Energética (formerly PROESCO), which focuses on actions that reduce the final energy consumption, and BNDES Finem - Eficiência Energética, focused on actions for increasing energy efficiency and consequently decrease final energy consumption (SITAWI, 2016).

3.4.3. Tax Policies

The tax policies aim to meet the need for resources and financing of the State, and to direct the behavior of economic agents based on fiscal measures. It is important to emphasize initially that the Brazilian fiscal system is specific and complex. The nature of the tribute is determined by the fact that it generates it. This is called the "generating event", which is one of the sources of the fiscal obligation (BRASIL, 1966). It can be classified as progressive, regressive or neutral (if the ratio increases, decreases or remains constant, respectively, with income growth), according to the variation in the relationship between the tax burden and the taxpayer's income (CAVALCANTI, 2006).

The tributes are instituted with the purpose of being collected. In the meantime, part of their collection may be waived for other purposes of State interest in order to encourage certain activities (e.g., industrial technological development) or development of certain regions. This fiscal renunciation has the technical name of "extrafiscality", which means its use for purposes other than the collection (AMARAL and OLENIKE, 2003). It should be noted that such fiscal waiver is an indirect form of executive power to finance the production or research of certain sectors of the economy. As a result, governments can, through development policies, create incentives for particular sectors of the economy, favoring decarbonisation of strategic sectors such as industry.

It should also be noted that taxes can take different forms in the national tax system: They are: taxes (*imposto*), charges (*taxas*) and improvement contribution[16]. The tax is the tribute whose obligation has, in fact, a situation that is independent of any specific state activity, characterized by not having its collection with specific destination, and is destined to meet the general needs of the public administration, without ensuring to the taxpayer any direct income in consideration to the portion paid (BRAZIL, 1966). In Brazil there are federal, state and municipal taxes. The charge, on the other hand, is intended to remunerate specific services, effectively rendered or made available to the taxpayer, having as a generator the regular exercise of police power, or the actual or potential use of a specific and divisible public service, provided to the taxpayer or made available to him/her (BRASIL, 1966). Therefore, it always corresponds to a direct consideration for the service received or made available, even if the taxpayer does not use it, as is the case of municipal water and sewage services, which, when existing and put into operation, always entail the requirement of the corresponding rate (AMARAL and OLENIKE, 2003). Lastly, the improvement contribution has the effect of generating real estate valuation that results from public works, as long as there is a causal link between the improvement and the accomplishment of the public works. According to Art. 81 of the National Tax Code, the improvement contribution charged by the Federal Government, the States, the Federal District or the Municipalities, within the scope of their respective attributions, is instituted to cover the cost of public works of which real estate valuation takes place, having as a total limit the expense incurred and as an individual limit the increase of the value that the work results for each property benefited.

Also, there are parafiscal contributions, which differ from the charges, since their generating facts are not activities of the State. Nor can they be characterized as taxes, since they have a specific destination (GIAMBIAGI and ALÉM, 2000). The Art. 149 of the Federal Constitution of 1988 establishes that it is solely the responsibility of the Union to institute social contributions, to intervene in the economic sphere and in the interests of the professional or economic categories, as an instrument for action in the respective areas, and Paragraph 1 of this article establishes that States, Federal District and Municipalities may impose a contribution, charged to its employees, for the costing of social security schemes of a contributory and solidarity nature, for the benefit thereof.

[16] Due to translation issues, misunderstandings often occur with relationship to different types of tributes. Often, carbon tax is translated as *"taxa de carbono*", when, in fact, it means *tributo sobre o carbono*.

In terms of the main instruments already in place, it is possible to highlight the Ecological ICMS, which is a fiscal mechanism that allows municipalities access to larger portions of the resources collected by the states through the Tax on Circulation of Goods and Services (ICMS) than those that they would already be entitled to, due to compliance with certain environmental criteria established by state laws (MCTI, 2016). Also, the Tax on Industrialized Products (IPI), regulated by Decree 7212, of June 15, 2010, consists of a tax on all industrialized products, national or imported, historically relevant as to the impact on the sale of vehicles, and consequently CO_2 emissions from the transportation sector, as well as the Motor Vehicle Property Tax (IPVA), which is a state tax levied annually on any owner of motor vehicles.

It is also worth mentioning the Contribution of Intervention in the Economic Domain (CIDE), which focuses on the importation and commercialization of gasoline and its chains, diesel and its chains, aviation kerosene and other kerosene, fuel oils, liquefied petroleum gas (LPG) and ethyl alcohol. Its contributors are the producers, formulators and importers of these fuels (CAVALCANTI, 2006), and the resources can be directed to the promotion of environmental projects. Lastly, another instrument, established from the Kandir Law, whose main objective is to exempt the payment of ICMS on exports of primary and semi-finished products or services, in addition to the use of credit for the acquisition of property, plant and equipment use as well as electric power (LEITÃO et al., 2012).

3.4.4. Climate Policies

Climate policies aim to encourage development in less carbon-intensive solutions, based on sustainability criteria. Some of them were analyzed in subsection 3.1., so they will be briefly presented and evaluated here. In terms of instruments, in 2009 the National Policy on Climate Change (NPCC) officialized Brazil's voluntary commitment to the UNFCCC to reduce GHG emissions between 36.1% and 38.9% of projected emissions by 2020, with a baseline of 3,236 $GtCO_2eq$ of GHG emissions by 2020. On December 9, 2010, Decree N^o. 7,390 was issued, which regulates some articles of the PNMC and imposes targets for GHG emissions by economic sectors. Unlike the preliminary estimates made by PNMC, Decree N^o. 7,390 establishes the baselines, and the total emissions of the mitigation scenario, without presenting more detail on each sector. The exception is the energy sector, as the government considered the Ten-Year Energy Plan (PDE) as a mitigation scenario, as it includes numerous efforts to increase energy efficiency, the share of renewable energy and nuclear energy in the energy matrix (EPE, 2010a).

Regarding the mitigation measures for the other sectors, there is no further detail, only some measures being mentioned without presenting a quantitative value of emission reduction (SANTOS, 2014). One of the conclusions is that the main contribution to reduce GHG emissions from Brazil would come from efforts to reduce deforestation in the Amazon (WILLS, 2013). Regarding industry specifically, Article 5 of the Decree states that the projection of national GHG emissions for the year 2020 is 3,236 million tCO_2eq, according to the methodological detail described in the Annex to this Decree (BRAZIL, 2010b).

As a result of these commitments, several sectorial plans were established under the NPCC, such as Climate Change Adaptation and Mitigation Sector Plan for the Consolidation of a Low Carbon Economy In the Manufacturing Industry (Industry Plan), with reduction target of 5% compared to the projected 2020 scenario (equivalent to 308.16 $MtCO_2eq$) of industrial process and energy use emissions (MDIC, 2013). The role of the goal is to stimulate the improvement of the efficiency of industrial processes and not to curb economic growth. In summary, the plan aims to ensure the continuity of Brazil's competitive development and prepare the sector to face the challenges of climate change. Also in the context of sectorial plans, there is the plan to reduce emissions from the steel industry (Steel Plan), which was based on technical and economic discussions on increasing the competitiveness of the steel industry in a sustainable way (MCTI, 2016a).

In 2015, by ratifying the Paris Agreement with Brazil's NDC, the country undertook to implement actions and measures to support a 37% reduction in GHG emissions in 2025 (equivalent to the emission of 1,346 million tCO_2eq), and 43% in 2030 (equivalent to the issuance of 1,208 million tCO_2eq), based on the levels recorded in 2005 (MMA, 2017). The document took into account initiatives for the three sectors with the largest participation in the Brazilian emissions profile in 2012 (Land Use, Land Use Change and Forestry – LULUCF, Energy and Agriculture).

When analyzing the treatment of the industrial sector in the Brazilian NDC, it is observed the existence of a generalist character, which boils down “to promote new standards of clean technologies and to extend measures of energy efficiency and of low carbon infrastructure". This creates opportunities, which are associated with the diversity of measures that can be implemented, especially when considering the heterogeneity of the productive processes of the key sectors of the Brazilian industry. Some examples are modernization of industrial plants, increase of productivity, optimization of the use of inputs, such as raw material, energy and fuel, reduction of operational and logistic costs, change of energy matrix and greater competitiveness in the international scenario, among others. On the other hand, such generalization makes it difficult to measure the emission efforts to be directed to the sector, as well as the potential results of the measures adopted (CEBDS, 2017).

3.4.5. Environmental Policies with Emphasis on Atmospheric Emission Control

The environmental policies with emphasis on atmospheric emission control aim to manage the emission of atmospheric pollutants from fixed sources[17] with a local impact range (NOx, SOx, Particulate Matter - PM). In this case, different instruments could be used singly or in combination, such as standards associated with technologies (for both emission control and industrial process - often referred to as best available technologies – BAT), emission standards for pollutants (associated with a concentration in exhaust concerning a fixed source), emission markets, emission taxation, etc. Brazil uses the command-and-control instrument of fixed source emission standards, defined by the National Council for the Environment (CONAMA).

Resolution Nº. 436/2011 defines emission limits established for some of the industrial segments comprehended in this thesis, among them: pulp, aluminum, chemicals, steel, cement and glass, and the generation of heat.

[17] They are those that occupy a relatively limited area, allowing a direct evaluation in the source. The sources classified as fixed refer to the activities of the industry of transformation, mining and production of energy through thermoelectric plants.

3.4.6. Summary of Policies and Instruments for the Industrial Sector

In order to systematize the main characteristics of the policies and instruments analyzed, Table 9 presents a summary of this information.

Table 9 – Summary of Policies and Instruments for the Industrial Sector
Source: Own elaboration

Policy	Objective	Instruments	Description and Analysis
Sectorial Stimulus Policies	To promote the growth of a specific industrial sub-sector, through BNDES financing programs, government purchases, and Local Content policies	Support Policies for R,D&I and Industry Financing	Support R,D&I and industry financing with the aim of stimulating the growth of economic sectors. Focus in support of FINEP and BNDES. However, such instruments, in some cases, encourage carbon-intensive sectors.
		Public Investments	The benefits can be summarized as the induction of a demand for products with more advanced technologies, less socio-environmental impact and the reduction of the risk inherent to R&D activities in the country.
		Local Content Policies	It consists in directing the national investments applied in a particular good or service, aiming at the development of the participation of the national industry. Examples in Brazil: upstream oil and gas and wind turbines.
Rational Use of Resources Policies	To stimulate policies for the rational use of resources in the country, focusing on the industrial sector, based on incentives for government programs, investments in R&D for energy efficiency and BNDES financing programs	Government Programs	Brazil has, for at least three decades, programs of rational use of resources, among them: Procel, Conpet, PNRS, Reverse Logistics, ISO 14,040, PNRH, among others.
		Investment in R&D for Energy Efficiency	Concessionaires and licensees of public electricity distribution services shall apply, on an annual basis, the minimum percentages of 0.5% for both research and development and for energy efficiency programs in the supply and final use of energy.
		BNDES Financing Programs	Main lines of financing: BNDES Energy Efficiency (former PROESCO) and BNDES Finem - Energy Efficiency.
Tax Policies	To direct the behavior of the economic agents to the consumption/production of goods/services less carbon-intensive, from tax measures	Taxes for Mitigation of Climate Change	Examples of tax measures: Ecological ICMS, IPI, IPVA, CIDE, among others. It is also worth noting that the Tax Reform process, currently under discussion in the National Congress, offers a unique opportunity to introduce tax instruments aimed at achieving environmental policy objectives. In this sense, it is necessary to evaluate the particular cases, but it is possible to highlight possible opportunities. For example, there is no specific tax regime for paper and cellulose, glass and lime. It is also worth mentioning the need for the tax policy to be aligned with the issue of pricing (for example, the reduction of IPI for automobiles, encouraging the purchase of cars).
		Kandir Law	Exemption from ICMS payment on exports of primary and semi-finished products or services, in addition to the use of credit for the acquisition of both fixed assets for use and electric energy.
Climate Policies	To reduce GHG emissions in order to meet the commitments of PNMC and, more recently, Brazilian NDC	National Policy on Climate Change (PNMC)	Quantitative targets for reducing GHG emissions for: LULUCF, energy, agriculture and industrial processes and waste treatment. However, there is no breakdown at the subsector level of the industry.
		Industry Plan	It aims to prepare the domestic industry for the future scenario in which carbon productivity will be as important as labor productivity and other factors to define the international competitiveness of the economy. However, it has a protectionist character with greater emphasis on ensuring competitiveness than on productivity gains.

		Steel Plan	It seeks to subsidize the development of public policies to encourage the use of sustainable charcoal from planted forests for use in the steel industry to promote emissions reduction, avoid deforestation of native forests and increase the Brazilian competitiveness of the iron and steel industry in the context of the low carbon economy.
		Brazilian NDC	Reduce by 37% in GHG emissions in 2025 (equivalent to the emission of 1,346 million tCO_2eq), and 43% in 2030 (equivalent to the emission of 1,208 million tCO_2eq), based on the levels recorded in 2005. This instrument currently represents the national commitment assumed under the Paris Agreement.
Environmental Policies with emphasis on Atmospheric Emission Control	To control emissions of air pollutants from fixed sources with local impact coverage (NOx, SOx, MP)	Pollutant emission standard	CONAMA Resolutions define emission standards of NO_x, MP, SO_x for fixed sources (natural gas boilers, fuel oil and biomass) and industrial processes (steel, cellulose, fertilizers, glass, etc.).

4. Assessing Domestic Vulnerability and International Trade Exposure of CPI

Domestic carbon pricing policies may impose adverse competitiveness risks on energy-intensive firms and industries competing against foreign firms that may bear a lower or zero price on carbon (ALDY, 2016). The risks of competitiveness effects include adverse economic outcomes, such as reduced production, lower employment, and higher net imports, besides adverse environmental outcomes, with the shifting of emissions-intensive activities to unregulated foreign markets (carbon leakage). For these reasons, it is fundamental to understand and evaluate the impacts of creating a CPI on the competitiveness of the industrial sector.

Thus, this chapter is divided into two sections, where the first one focus on a qualitative assessment while the second one focuses on the methodologies and quantitative assessment criteria from some jurisdictions, describing, evaluating and comparing their indicators. After that, these indicators are applied to the Brazilian industry sector, in order to assess the risk of carbon leakage in the subsector level.

4.1. Qualitative Assessment

Initially, the interaction analysis between existing sectorial polices and CPIs is carried out, following to the evaluation their different designs in terms of allocation methods (ETS case) and recycling ways (carbon tax case). As in the section 3.4., this qualitative assessment was also developed in the context of the Component 1 of the Brazilian PMR Project, so the effects on sectorial policies and the impacts from different CPI designs will be discussed and analyzed. Details about each qualitative assessment, as well as the justifications for their development, are presented in the following subsections.

4.1.1. Effects on Sectorial Policies

In this subsection, a short qualitative discussion on the impact of carbon pricing on the goals set by existent sectorial policies. Such analysis is justified by the need of aligning selected policies with those linked to carbon pricing. Still within the qualitative framework, the following effects will be identified: (i) effects on the agents' competitiveness; (ii) effects on social impacts focusing on the consumers' purchasing power; and (iii) effects on the national level of emissions of GHG. In this way, it is possible to build a matrix of political interaction and carbon pricing, where the interactions can be classified as positive, negative, neutral, or uncertain.

4.1.1.1. Sectorial Stimulus Policies

Policies to stimulate sectors, especially financing programs and R,D&I, use instruments that tend to push industrial competitiveness. However, whether this will lead to lower prices to the end consumer will depend on the sector capacity to absorb competitiveness gains into profits. This occurs, for instance, in sectors whose prices are formed in the international market. The effect in terms of emissions associated to this policy, on the other hand, is uncertain, as it depends on which sectors, processes and products that were favored.

Investments in infrastructure, though, can have positive effects either on the competitiveness or purchasing power. This result is achieved by the reduction of logistic costs and improvement of market conditions for the industry. Industrial emissions, in this case, would not be directly impacted, although emissions in the transportation sector may be reduced.

Concerning the local content (LC) policy, despite the possibility of spurring the development of new products and processes, which could enhance competitiveness and reduce prices, the observed results for this policy instrument in Brazil show that it was not successful as it should have been (ALMEIDA, 2015). Thus, although it secured a piece of the market for Brazilian industrial products, it did not boost competitiveness in these sectors per se. On the other hand, this led to higher production costs that were translated into higher cost pass-through. Finally, whereas the LC policy ended up encouraging energy-intensive sectors, its effect on the emission was negative, meaning that it caused an increase of emissions. However, it is important to make clear that LC has not only impacts on sectors like oil and gas and wind power, but especially in sectors that demand products from these sectors.

Carbon pricing could generate resources to support industrial sectors, causing positive outcomes for them through the identified instruments. Notwithstanding, the impacts on the goals of sectorial stimulation policies will depend on the relation between activity effects and subsectorial intensity, as well as on the allocation mechanisms – the usage of emission allowances can negatively affect sectorial stimulation, for instance – and tax recycling, the reason why this impact is rather seen as uncertain.

4.1.1.2. Rational Use of Resources Policies

Policies of rational resource use encompass instruments that seek to increase efficiency in the usage of energy and/or materials. This includes both the rational use of electricity and fuels, as well as the better use of water and waste recycling. Such efficiency gains are achieved through government programs, R&D investments, and special funding lines. By promoting the rational use of resources and raising the productivity of the factors of production, these instruments result in the competitiveness of industrial sectors by increasing efficiency and reducing costs. These competitiveness gains, in turn, can be passed on to product prices, having a positive effect on the purchasing power of the population. Finally, by promoting energy efficiency, such programs also help to reduce GHG emissions by the industrial sector.

Carbon pricing has positive impacts for all analyzed subsectors, since this instrument is aligned to the policy of encouraging the rational use of resources, especially the non-renewable ones.

4.1.1.3. Tax Policies

Tax policies seek to guide the behavior of economic agents through taxation measures that alter the relative prices of products. However, tax policy has been used in Brazil mainly as a stimulus policy through incentives and tax exemptions. Thus, despite the impacts on the government budget, these policies have had positive effects on the competitiveness of industrial sectors and on the purchasing power of the population. On the other hand, the effects on emissions have been negative, since such exemptions fall heavily on primary and semi-finished products, whose production process tend to be energy-intensive.

Although carbon pricing contributes to drive agents' behavior, tax policies in Brazil, as mentioned before, have been focusing on tax exemption for energy-intensive sectors[18]. For this reason, it was estimated that carbon pricing has an uncertain effect on the policy goals, and it could have positive impacts on the government's revenue, but also neutral or even negative, in the case of long-term tax exemptions.

4.1.1.4. Climate Policies

Climate policies encompass instruments that aim to reduce GHG emissions in Brazil. In theory, these policies and their instruments would have a positive effect on emissions, what is their primary objective. In general, however, it is not possible to assess the effects of some of these instruments on the competitiveness of industrial sectors and on the purchasing power of the population, as there is still no clear definition of the mechanisms to should be used to achieve the very goal of reducing emissions. Having said this, the effects on competitiveness and purchasing power are still uncertain.

The exceptions would be the Industry and Steel Industry Plans, in which there is an explicit statement of looking forward to maintaining, or even increasing, the sectors competitiveness by reducing GHG emissions. Although these competitiveness gains could generally be passed on in form of lower prices (creating a positive effect on purchasing power), in the case of segments with prices formed in the international markets this would not occur. This is the case, for example, of the Steel Plan.

Regarding the Brazilian NDC, although it has a positive effect on emissions, the impacts on competitiveness and purchasing power are not clear. On the one hand, NDC predicts an increase in energy efficiency, which could stimulate competitiveness, with possible price pass-through. On the other hand, mitigation options in the energy production and transformation sectors (such as exploration and production – E&P, refining, electricity generation and biofuels) can raise the price of energy for the industrial sector, having a negative effect on competitiveness and purchasing power.

In this case, carbon pricing is one of the possible mechanisms to meet the established policy goals. Carbon pricing has also a positive impact on policies goals, considering the

[18] In this thesis, tax exemption are considered as part of the tax policy and not as a sectorial stimulus policies.

commitments agreed upon by the National Policy on Climate Change (NPCC) and, more recently, by the Brazilian NDC in order to reduce GHG emissions, and the need to discuss goals and funding to achieve policies and plans.

4.1.1.5. Environmental Policies with Emphasis on Atmospheric Emission Control

Environmental policies to control atmospheric emissions of local pollutants aim to improve air quality, especially in urban centers. The effect of such policies is generally negative on competitiveness, purchasing power and emissions. This is due to the fact that most of the technologies to control local pollution generate costs for industrial plants, despite generating benefits in terms of better local air quality. This is the case with end-of-pipe equipment to control pollution, as well as the specification of fuels.

Similarly, as end-of-pipe equipment to control pollution entails energy penalties (energy consumption of such equipment), there would be a negative effect on GHG emissions since industrial plants would increase their energy consumption. Likewise, a policy of specifying fuels in refineries[19] would increase both the cost of fuel and the GHG emissions associated with its production (SZKLO and SCHAEFFER, 2007).

Interestingly, the opposite is not true. Emissions of local pollutants are largely associated with the combustion of fossil fuels, so policies to reduce GHG emissions would have a co-benefit in terms of reducing the emission of local pollutants.

Exceptions have to be considered, though. In the case of controlling local air pollutants based on the control of combustion (as opposed to the specification of fuels and end-of-pipe technologies), there could be a simultaneous reduction of local and global emissions. According to the project "Mitigation Options of Greenhouse Gas Emissions in Key Sectors in Brazil", some measures of this type can be cost-effective, generating favorable effects for competitiveness and, eventually, purchasing power (MCTI, 2016). This is the example of low-NOx burners, where the NOx emission reduction is due to a more

[19] Although the refining sector is not being analyzed among the other sectors in this thesis, it can pass on the costs of fuel specification to consumer sectors, including the industry, increasing its production costs and affecting competitiveness.

efficient burning generated by the air-fuel ratio adjustment, which in turn increases the efficiency of the combustion leading to a lower fuel consumption.

Carbon pricing has positive impacts for all subsectors, as it provides greater control of atmospheric emissions by air pollutants coming from fixed sources and with local impact coverage (NOx, SOx, MP) by the agents.

4.1.1.6. Summary of CPI on Sectorial Policies

Table 10 summarizes the impact of the five policy goals considering variables like competitiveness, end consumer's purchasing power, and national GHG emission by using different policy instruments.

Table 10 – Summary of CPI impacts on sectorial policies
Source: Own elaboration

Policy	Effects of Interactions between Policy and CPI	Instruments	CPI Impacts		
			Competitiveness	**Purchase Power**	**GHG Emissions**
Sectorial Stimulus Policies	Uncertain: Carbon pricing could provide resources to support sectors. Impact will depend on the relationship between subsector effects and intensity	Support Policies for RD&I and Industry Financing	Positive: This is the prime goal of this policy	Uncertain: It depends on the producer's ability to maintain margin (ensuring the generation of new products at lower cost, such as pharmaceuticals)	Uncertain: Depends on the focus of the RD&I and funding
		Public Investments	Positive: Investments in infrastructure (e.g., reduction of logistics costs)	Positive: Infrastructure investments can reduce costs, leading to lower prices	Neutral: Neutral impact on industry
		Local Content Policy	Positive: Does not increase the competitiveness of sectors per se, but it guarantees market	Negative: In the short term, negative. In the long term, it depends on the effect of the policy	Negative: Tends to stimulate energy-intensive segments
Rational Use of Resources Policies	Positive: Positive impacts for all subsectors, as they encourage the rational use of resources, especially non-renewable ones	Governmental Programs	Positive: They can promote more efficient processes, improving efficiency and reducing costs	Positive: Efficiency gains can be passed on to the price	Positive: Synergistic effect between energy efficiency and combustion emissions
		Investment in RD&I and Energy Efficiency	Positive: stimulates the productivity of the factors of production		
		Financing Programs of BNDES			
Tax Policies	Uncertain: Carbon pricing helps drive agent behavior. However, tax policies have been focusing on exemption for energy-intensive sectors	Taxes to Mitigate Climate Change	Positive: Tax incentives	Positive: Fiscal stimulus can reduce the price of the product to the consumer	Negative: Focused on energy-intensive sectors (e.g., Kandir Law)
Climate Policies	Positive: Carbon pricing is one of the possible mechanisms to meet the goals of this policy	National Policy on Climate Change	Uncertain: There are no instruments defined that can directly affect competitiveness	Uncertain: There are no instruments defined that can directly affect purchasing power	
		Industry Plan	Positive: Explicitly, it seeks to reduce emissions without compromising		

			competitiveness (doable by increasing productivity of the factors of production)	Positive: Explicitly, it seeks to avoid reduction of consumption due to higher prices	Positive: This is the prime goal of this policy
		Steel Plan	Positive: Explicitly, it seeks to increase the competitiveness of the iron and steel industry	Neutral: Prices formed in the international market	
		Brazilian NDC	Uncertain: Although it mentions energy efficiency, it can raise the cost of electricity	Uncertain: Can raise the cost of industrial products (indirect electricity effect)	
Environmental Policies with emphasis on Atmospheric Emission Control	Positive: Positive impacts for all sub-sectors	Pollutant emission patterns	Negative: Control costs (except by the more efficient burners, e.g. low NO_x burners)	Negative: Costs can be passed on to the price	Negative: Energy penalty for end-of-pipe control equipment (preserving control via more efficient burning)

4.1.2. Effects from Different CPI Designs

This subsection will also conduct a qualitative analysis on the impact of different CPI designs - considering variations in allocation methods (in the ETS case) and recycling forms (in the carbon tax case) - on the industrial subsectors in terms of (i) competitiveness of the sectors; (ii) social impacts, from the point of view of effects on consumers' purchasing power; and (iii) national GHG emission levels. The goal of this analysis is to construct a matrix that evaluates the effects of the different CPI designs on the industrial subsectors, being able to be classified as positive, negative, neutral or uncertain, in order to follow the same classification of the previous subsection.

4.1.2.1. ETS: Allocation Methods

The different forms of allowances allocation follow the CPLC (2016) pattern, aligned to the previous discussion presented in the “Mitigation Policies for Carbon Leakage” subsection (2.3.2). They are: auctioning; grandfathering, sectorial benchmark; and output based. The forms of allocation will be briefly discussed in light of the effects on industrial sectors competitiveness, purchasing power and GHG emissions, and finally, the interaction matrix will be presented, summarizing the analyzes.

Regarding sectorial competitiveness, the impacts were analyzed based on the economic characterization carried out in section 3.2., which considers the export coefficients, as well as the Gross Value of Production (GVP) and the Value Added (VA) of the subsector. The allocation of permits can generate both losses of competitiveness for sectors with lower capacity to pass through costs, depending on the price formation in the international market, and opportunities for extraordinary profits, for sectors with a higher market concentration index.

Having said that, such impacts on the competitiveness can affect consumers’ purchasing power, which is the second point assessed by the interaction matrix. Concentrated sectors and with low external vulnerability are better able to pass through prices of inelastic products, without market share loss. That is, the firm can impose a price markup and transfer carbon costs to end consumer.

The third impact assessed is the national GHG emissions. In this case, unlike carbon taxation - which will be evaluated in the next subsection -, the impacts on GHG emissions may be uncertain or, possibly, neutral, according to the permit distribution criterion.

Regarding the allocation of permits through an **auction system**, the impacts on competitiveness were evaluated as negative in all cases, since this allocation method represents an additional cost for subsectors being held down by external competition. As for the impacts on consumers' purchasing power, they were evaluated as neutral in most cases, because the price is formed in the international market. The exception is the case of the cement, lime and glass sectors, where the impact is negative since such sectors face low external competition.

The assessment is positive for all subsectors considering national GHG emissions, in the case of the allocation mechanism of allowances by auction. It should be noted that in a market in equilibrium, as discussed in section 2.1., the price resulting from the auction reflects the marginal cost of the externality (GHG emissions), being equal the optimal level of a Pigouvian tax ($t^* = CMg$), by incorporating the difference between the marginal social cost (which considers the external costs of production) and the marginal cost of the firm (i.e., its supply curve). In this sense, international experience highlights the need to include additional mechanisms to ensure price stability and market equilibrium. According to the discussion presented in section 2.2., in Europe, for example, EU ETS sought to reduce price volatility by including rules that automatically change the auctioned volumes when the volume of permits is exceeded, while California included lower limits and price signals to assure the correct price signal and maintain incentives for mitigation.

International experience also shows that the equilibrium in the allowance market is also affected by free permit donations (**grandfathering**). Such donation does not generate revenues that would be priced in the allowance market (double dividend, similar to the carbon tax case), becoming a high social cost and not reflecting the heterogeneity among the polluting agents that participate in the market (GOULDER et al., 1996). Therefore, in terms of competitiveness, purchasing power and GHG emissions, the impacts are necessarily uncertain, except for the offsets that will be dealt with later, in particular in chapter 5. However, it is important to draw attention to the fact that, since donating the emission certificates rather than charging for them does not create an extra burden economic agents (auctioning), this policy design has been widely adopted at the beginning of the implementation of carbon markets, as shown in the section that analyzes the international experience (section 2.2.), exactly because it reduces the impact on such sectors right at the beginning of the CPI operation, evolving over time towards the charging for the certificates (auctioning).

Besides, the free allocation of permits requires attention. Free allowances should ensure flexibility for new agents to participate in the market. In the EU ETS, for example, there is a fund for financing clean technologies (NER 300) that is funded by emissions permits and it acts as a reserve fund for 300 million new permits (EUROPEAN COMMISSION, 2017).

Considering the method of permits allocation based on the past production of benchmark companies (**sectorial benchmark**), the impact on the competitiveness of the subsectors Cement, Lime and Glass, and Steel was assessed as positive, since the national average of this sector is below world average specific consumption. The evaluation is also positive for the subsector Paper and pulp, which shows a competitive advantage for its use of biomass as input. For the Aluminum subsector, the impact on competitiveness is neutral, since its specific consumption is equivalent to the international average. However, for the Chemical subsector, there is a negative impact due to the existing concentration of this subsector in segments with low added value and high-energy intensity.

Still regarding the sectorial benchmark, the impacts on purchasing power were evaluated as neutral, due to price formation in the international market. However, for the Cement, Lime and Glass subsectors, the impact is uncertain since the benchmark permit allocation may generate (implicit) cost or subsidy, depending on the benchmark definition. Regarding national GHG emissions, the impacts are mostly uncertain, as they are definition-dependent. There are, however, positive impacts identified for the Chemical subsector, but neutral effects associated to the Pulp and Paper subsector. It is important to note, however, that a benchmark cap-and-trade system should always seek to use benchmarks that generate some mitigation efforts by the sectors involved in order to achieve a reduction in total emissions.

Considering the emissions intensity-based allocation method (**output based**), that is, sectorial or based on the company's historical values, assessed together with current production data, it is seen that the impact on competitiveness, purchasing power and the emissions, for all cases, is rather uncertain, since the criterion used to distribute the permits may generate costs or subsidy (implicit) to the subsectors. This result depends on the definition of the production criterion, for example, the period or year associated with it. If one defines a period of time (or year), in which the emissions of that sector are smaller than the ones today, it will show a cost to handle its current emissions; otherwise, it will show an emission credit that the sector can negotiate, what will represent an implicit subsidy.

Table 11 presents a summary concerning the impacts, achieved by a qualitative assessment, of the permits allocation on the competitiveness of the industrial segments analyzed, on the final consumer's purchasing power and on national GHG emissions.

Table 11 – Impact of the allocation methods on the competitiveness, purchasing power and GHG emissions of the industrial segments analyzed

Source: Own elaboration

Allocation Methods	Sector	CPI Impacts		
		Competitiveness	Purchase Power	GHG Emissions
Auctioning[20]	Aluminum	Negative: Additional cost. External competition	Neutral: Price formed in the international market	Positive: Reduction of GHG emissions
	Cement, Lime and Glass	Negative: Low margins. Additional cost.	Negative: Low margins. Pass-through of costs to prices (low external competition)	
	Chemicals	Negative: Additional cost. External competition	Neutral: Price formed in the international market	
	Pig Iron and Steel	Negative: Price formed in the international market	Neutral: Price formed in the international market	
	Pulp and Paper	Negative: Additional cost. External competition (Pulp)	Negative: High Brazilian market share may influence international (and domestic) price	
Grandfathering	Aluminum	Uncertain: The permission distribution criteria can generate cost or subsidy (implicit)		
	Cement, Lime and Glass			
	Chemicals			
	Pig Iron and Steel			
	Pulp and Paper			
Sectorial Benchmark	Aluminum	Neutral: Segment equivalent to the international average	Neutral: Price formed in the international market	Uncertain: It depends on benchmark setting

[20] The impacts of the auction on competitiveness were evaluated as negative, since at first there will be an additional cost related to the price of the allowances on economic agents. Certainly, recycling of this revenue could mitigate such impacts.

Allocation Methods	Sector	CPI Impacts		
		Competitiveness	Purchase Power	GHG Emissions
	Cement, Lime and Glass	Positive: The national standard of the segment is below the world average specific consumption	Uncertain: It can generate cost or (implicit) subsidy	Uncertain: Some installations may not reduce emissions
	Chemicals	Negative: Concentration in segments of low VA and high energy intensity[21]	Neutral: Price formed in the international market	Positive: Reduction of GHG emissions
	Pig Iron and Steel	Positive: The national standard of the segment is favored by the consumption of charcoal	Neutral: Price formed in the international market	Uncertain: It depends on benchmark setting
	Pulp and Paper	Brazilian competitive advantage for the biomass input	Neutral: Advantage absorbed as margin for the producer	Neutral: neutral impact in this subsector
Output based	Aluminum	Uncertain: The permission distribution criteria can generate cost or subsidy (implicit)		
	Cement, Lime and Glass			
	Chemicals			
	Pig Iron and Steel			
	Pulp and Paper			

[21] Evaluation of the Brazilian Chemical subsector according to existing plants.

4.1.2.2. Carbon Tax: Recycling Alternatives

The different forms of recycling, that is, different destinations for tax revenues, also follow the pattern presented in CPLC (2016). These are: reduction of other taxes; support to families; support the industry; investment in climate funds; and the budget of the central government. Recycling methods will be briefly discussed in light of the effects on the competitiveness of industrial sectors, purchasing power and GHG emissions, considering the specific effects on the subsectors analyzed.

Considering the sectorial competitiveness, the impacts were analyzed based on the economic characterization presented in section 3.2., which takes into account the sectorial export coefficients as well the Gross Value of Production (VBP) and the Added Value (VA) of the subsector. It is important to note that carbon taxation leads to additional risk of vulnerability due to the loss of the domestic market in import parity or loss of market for exporters in the export parity.

In turn, the impacts of taxation on competitiveness may affect consumers' purchasing power, the second aspect evaluated in interaction matrix (Table 12). Therefore, a concentrated sector with low external vulnerability may impose higher prices onto a less elastic product to prices, without losing market share. That is, the company can impose a price markup, transferring the carbon cost to the consumer.

The third impact evaluated is the national GHG emissions. In this case, because it is the first goal of carbon taxation, the impacts were seen as positive in all situations. Nevertheless, in the case of cap-and-trade, it is possible that the effects on GHG emissions could be uncertain or, possibly, neutral.

Recycling carbon tax through the **reduction of other taxes** may reach tax revenue neutrality, i.e. the amount of money collected thorugh a carbon tax is equivalent to the exemption of other taxes. Compensation through the reduction of notably regressive taxes, such as ICMS, PIS and COFINS, has advantages such as reducing tax distortions related to the tax burden, improving the efficiency of the tax system, and encouraging economic activity (in line with the discussion on Tax Reform). The reduction of other taxes, however, could reduce the effectiveness of carbon taxation, generating distortions among agents, according to the policy design (CPLC, 2016). These policies, however, may have negative effects especially in the long term on industrial competitiveness.

For carbon intensive sectors, such as Cement, Lime, Glass and Steel, it has been assessed that tax neutrality will hardly exist. Therefore, the impact of carbon taxation with recycling through the reduction of other taxes could have negative effects on the competitiveness of these subsectors. In low carbon intensive subsectors, such as Pulp and Paper, whose main energy source is derived from biomass, carbon pricing may have less impact than tax reductions, generating positive effects on its competitiveness. The effects on the competitiveness of the subsectors Pig Iron and Steel and Chemicals are uncertain and will depend, in addition to the carbon intensity, on the value of the tax. Also, in the case of the chemical industry, the heterogeneity of the sector shows that the effects on competitiveness vary according to the segment analyzed. In terms of purchasing power of consumers, the effects depend mainly on the ability of these subsectors to pass on costs to final consumers. Such a form of recycling has a neutral effect for most subsectors, as prices are formed internationally (with the exception of Cement, Lime and Glass). This effect is uncertain in the case of the chemical segment, since final consumption has a crucial role in some particular cases.

Carbon taxation, when its revenue is intended to go to households, can be done through direct transfers, by reducing taxes on households (for example, individual income tax - IIT), through subsidies or welfare assistance programs, similar to Bolsa Família). It can reduce the impacts of the increased cost of carbon taxes on household purchasing power, for example by reducing the economic impact of electricity price and its primary sources, such as coal.

Also, it can generate an increase in demand, having a positive effect on sectors whose proportion of sales of final goods is relevant. Regarding competitiveness, it was seen that subsectors with high intermediate consumption and export sales might suffer negative impacts, such as Cement, Lime, Glass, and Pig Iron and Steel. For the subsectors Pulp and Paper, and Chemicals, the impacts are uncertain, due to different weight distribution of intermediate and final consumption, and exports, respectively, in sales. Regarding purchasing power, the impacts of carbon tax revenue transferred to households are, of course, always positive in all subsectors evaluated. A caveat about this type of revenue recycling is that it may generate indirect emissions increase through a rebound effect. This happens when the increased family income leads to higher consumption and, thus, higher emissions.

Carbon tax revenue **aimed at supporting the industry** can be accomplished through production and investment financing, tax credits, support to R,D&I, or through energy efficiency programs. In this case, diminishing the opposition within industrial subsectors to carbon taxation is an advantage. However, it is necessary to ensure that tax recycling does not cause distortions and reduces the competitiveness of specific subsectors to the detriment of others. Due to the many available forms of support to the industry, it has been assessed that the impacts on competitiveness are uncertain in all cases. Although there are notably positive effects (such as innovation in more efficient products and processes), in the Brazilian case, this support has historically been associated with tax exemptions and tax credits (MACIEL, 2010). Therefore, we see that, the way in which the recycling carried out via support to the industry is made is of paramount importance for the competitiveness of the sectors. In any case, the impacts on the competitiveness of the sectors more intensive in carbon can be expected to be greater because of their greater exposure to carbon taxes.

The impacts of the carbon tax to support the analyzed industrial subsectors on purchasing power vary from uncertain to neutral, according to each subsector. The uncertainty comes from the weight of final consumption on sales, for some subsectors, such as Chemical and Pulp and Paper. For the other subsectors, the impact on consumers' purchasing power, due to price formation taking place in the international market, was neutral.

Revenue coming from carbon taxation can be channeled to investments in **climate funds** that target research and innovation in energy efficiency, infrastructure development or even by establishing international commitments (climate finance).

Regarding competitiveness, the effects depend essentially on the destination of the fund, which is why its impacts are uncertain. Nevertheless, the impacts on the competitiveness of sectors more intense in carbon can be expected to be greater because of their greater exposure to carbon taxes. The impacts on purchasing power vary from uncertain to neutral, according to each subsector. As in the case of industry support, the uncertainty is also due to the weight of final consumption on sales, for some subsectors, such as Chemical and Pulp and Paper. For the other subsectors, the impact on consumers' purchasing power was assessed as neutral due to the price formation taking place in the international market.

Finally, carbon tax revenue is allocated to the **central government budget**, and it can be allocated to several areas, according to the priority set for the public spending. Although this approach seeks flexibility in the tax revenue expenditure, the lack of transparency and control of public spending are challenges, especially in the Brazilian case. In this sense, when revenue is destined to the central government budget, the environmental benefit of carbon pricing may not be clear (CPLC, 2016).

Concerning competitiveness, the effects are negative for all subsectors analyzed, since tax revenue would hardly be used for improvements in the competitiveness of industrial subsectors. The impacts on purchasing power are neutral for most of the subsectors, given the price formation taking place in the international market. There are negative impacts identified in the case of Cement, Lime and Glass, since prices are formed domestically. There is some uncertainty regarding the impacts on purchasing power in Chemical, due to the heterogeneity of segments within the chemical industry.

From the debate on the impacts on competitiveness, purchasing power and emissions due to the different forms of recycling, Table 12 summarizes now the effects of carbon taxation on the industrial sectors analyzed according to the destination of such a tax.

Table 12 – Impact of the recycling ways on the competitiveness, purchasing power and GHG emissions of the industrial segments analyzed

Source: Own elaboration

Recycling Ways	Subsector	CPI Impacts		
		Competitiveness	Purchase Power	GHG Emissions
Reduction of other taxes	Aluminum	Uncertain: It depends on the intensity of carbon and the tax value	Neutral: Prices formed in the international market	Positive: Reduction of GHG emissions
	Cement, Lime and Glass	Negative: Intensive carbon sector, so tax neutrality will hardly exist	Negative: Cost can be passed through to the consumer	
	Chemicals	Uncertain: It depends on the intensity of carbon and the tax value	Uncertain: High weight of final consumption in some specialty chemicals	
	Pig Iron and Steel	Uncertain: It depends on the intensity of carbon and the tax value	Neutral: Prices formed in the international market	
	Pulp and Paper	Positive: Main energetic derived from biomass (carbon pricing may have less impact than reduction of taxes)	Neutral: Prices formed in the international market	
Support to families	Aluminum	Negative: High weight of intermediate consumption and exports in sales	Positive: The main objective of this recycling way is to positively impact the household purchasing power	Positive: Reduction of GHG emissions
	Cement, Lime and Glass	Negative: High weight of intermediate consumption in sales		
	Chemicals	Uncertain: High weight of final consumption in some specialty chemicals		
	Pig Iron and Steel	Negative: High weight of intermediate consumption and exports in sales		

Recycling Ways	Subsector	CPI Impacts		
		Competitiveness	Purchase Power	GHG Emissions
	Pulp and Paper	Uncertain: Pulp: high weight of exports in sales; Paper: high weight in intermediate and final consumption in sales		
Support the Industry	Aluminum	Uncertain: Due to the plurality of forms of industry support, for example, production and investment financing, tax credits, PD & I support or through energy efficiency programs. It is also necessary to ensure that recycling ways of the tax does not cause distortions and reduces the competitiveness of specific subsectors to the detriment of other	Neutral: Prices formed in the international market	Positive: Reduction of GHG emissions
	Cement, Lime and Glass		Neutral: Prices formed in the international market	
	Chemicals		Uncertain: High weight of final consumption in some specialty chemicals	
	Pig Iron and Steel		Neutral: Prices formed in the international market	
	Pulp and Paper		Uncertain: High weight in intermediate and final consumption in sales	
Investment in climate funds	Aluminum	Uncertain: It depends on the destination of the fund	Neutral: Prices formed in the international market	Positive: Reduction of GHG emissions
	Cement, Lime and Glass		Neutral: Prices formed in the international market	
	Chemicals		Uncertain: High weight of final consumption in some specialty chemicals	
	Pig Iron and Steel		Neutral: Prices formed in the international market	
	Pulp and Paper		Neutral: Prices formed in the international market	
Central government budget	Aluminum	Negative: Negative effect, because tax revenue would hardly be reversed for improvements in the competitiveness of industrial sub-sectors	Neutral: Prices formed in the international market	Positive: Reduction of GHG emissions
	Cement, Lime and Glass		Negative: Given that prices are formed domestically	
	Chemicals		Uncertain: Due to the heterogeneity of segments of this industry	
	Pig Iron and Steel		Neutral: Prices formed in the international market	
	Pulp and Paper		Neutral: Prices formed in the international market	

4.2. Quantitative Assessment

This section analyses the methodologies and quantitative assessment criteria from some jurisdictions, describing, evaluating and comparing their indicators, especially focused on carbon cost, emissions intensity, and trade intensity. Subsequently, these indicators are applied to the Brazilian industry sector, in order to assess the risk of carbon leakage at the subsector level.

4.2.1. Methodologies for Analyzing Carbon Leakage Exposure

Both quantitative and qualitative tests can be used to assess the risk of carbon leakage for different sectors (MARCU et al., 2014). This section examines the quantitative options available to test whether the risk factors are in a range that would indicate a risk of carbon leakage.

In general, quantitative tests use factors that can be quantified and result in a number that can be tested against benchmarks. Two main categories of quantitative tests are currently identified:

- Carbon-related risk tests;
- Trade exposure-related risk tests.

Each of these two categories can be further divided into approaches with different characteristics as will be shown in the next subsections.

These risk tests can be used alone or in a combination (i.e. multiple tests bundled together). Risk tests for carbon and trade intensity have often been used together to provide a better coverage and capture of the combined effects of carbon leakage risk factors. When risk tests are used in combinations, the thresholds are usually lower, as the tests are multidimensional and are intended to capture multiple conditions (MARCU et al., 2014). Also, quantitative and qualitative risk tests can be also combined.

There are several design features of risk tests that must also be taken into account when assessing risk tests. One design feature is whether the carbon leakage risk test employs an in/out (i.e. a sector is either at risk, or not at all), or a tiered approach. An in/out approach determines which sectors are or are not at risk and results in some sectors not receiving any compensation, if the sector falls under the threshold (WANG et al., 2017). With a tiered approach several risk levels are defined and compensation could be distributed in proportion to the risk level.

Another design feature that needs to be considered is the flexibility of the mechanism to adapt to changes in key parameters, including how it is updated. In general, mechanisms can be reviewed periodically and/or be triggered by market participants. This must be balanced with the need for stability for investment purposes.

Lastly, data availability and data aggregation are other important design features used in assessing risk tests. The underlying data for the risk tests may not always be publicly available, which creates problems with transparency. Moreover, data aggregation for sectors could be done at different levels and therefore sectors and risk tests may not be comparable across schemes (SATO et al., 2015).

The remaining parts of this section will discuss the different risk tests that are used in some jurisdictions, and then a comparison among them will be carried out considering some features. The choice of these jurisdictions was due to (i) its usage by different CPIs in the industrial sector, (ii) the complexity of the methodology, and (iii) for being considered methodologies already established, often used as a basis and/or reference for new methodologies in development.

4.2.1.1. European Union Emissions Trading System (EU ETS)

One of the central debates surrounding the design of the EU ETS was the approach to address carbon leakage concerns (SATO et al., 2015). Correctly identifying the economic activities exposed to the risk of carbon leakage represents the first step in mitigating the risk effectively.

The revised version (2009/29/EC) of the EU ETS Directive (2003/87/EC) and the Carbon Leakage Decision (2010) established the assessment rules for Phase 3 (2013-2020). A sector's leakage risk is established based on two quantitative criteria (EUROPEAN PARLIAMENT and EUROPEAN COUNCIL, 2009):

- The additional production costs defined as the sum of direct and indirect carbon costs divided by the Gross Value Added (GVA) of a sector.

- The trade intensity of this sector with countries that are not part of the EU ETS, defined as the ratio between the total value of exports to third countries plus the value of imports from third countries and the total market size for the Community (annual turnover plus total imports from third countries).

They are used as a stand alone, but also combined with one another (BRUYN, NELISSEN and KOOPMAN, 2013a).

Article 10a, pars.15-17 of the revised ETS Directive outline when a sector or subsector is deemed to be exposed to a significant risk of carbon leakage. Four criteria were given, if a sector would qualify for one of these, it would obtain free allocation of allowances (EUROPEAN PARLIAMENT and EUROPEAN COUNCIL, 2009).

1. Direct and indirect costs increase production costs by at least 5% of GVA and trade intensity is over 10%;
2. Direct and indirect costs increase production costs by at least 30%;
3. Trade intensity is over 30%;
4. For sectors that would not qualify under one of the above situations, a provision has been made for more detailed analysis at a more disaggregated level (NACE[22] 6 and beyond) and/or a qualitative assessment[23] if trade intensities and/or increase in production costs were close to the threshold levels in which the required investments, market characteristics and profit margins would flourish as alternative indicators.

The revised EU ETS Directive states furthermore that every year sectors can be added to the list based on the fourth criteria (ZAKLAN and BAUER, 2015). A structural revision of the Carbon Leakage List (CLL) is foreseen for every five years by the European Commission (EUROPEAN PARLIAMENT and EUROPEAN COUNCIL, 2009). During this structural revision, (sub)sectors can be added to or removed from the list. The first of such revisions was completed by the end 2014, and it was used for the allocation in the period 2015-2019 (BRUYN, NELISSEN and KOOPMAN, 2013a).

[22] The Statistical classification of economic activities in the European Community, abbreviated as NACE, is the classification of economic activities in the European Union (EU); the term NACE is derived from the French *Nomenclature statistique des activités économiques dans la Communauté européenne*.

[23] The qualitiative criteria includes: (i) emissions levels and electricity consumption reduction potential of individual installations in the sector; (ii) current and projected market characteristics and; (iii) profit margins as an indicator of long-term investment or relocation decisions (ZAKLAN and BAUER, 2015).

4.2.1.1.1. Carbon Cost (CC)

Carbon costs relative to value added is the approach currently used in the EU and which was also included in the proposed Waxman Markey Bill (American Clean Energy and Security Act), approved by the US House of Representatives in June 2009 but defeated by the Senate in the US. It consists:

$$CC = \frac{(Direct\ Emissions\ tCO_2 + Indirect\ Emissions\ tCO_2) * Carbon\ Price/tCO_2}{Gross\ Value\ Added} \quad \text{(Equation 1)}$$

As mentioned before, this test is currently used as a stand-alone, or in combination with another test. In the EU ETS, two thresholds are defined for this test. A carbon price of €30/tonne is used in calculating carbon costs (EUROPEAN PARLIAMENT and EUROPEAN COUNCIL, 2009).

When used as a stand-alone test, the carbon cost threshold is 30%. This figure was adopted in order to include outlying sectors with high carbon costs that needed to be included. When used in conjuction with the other quantitative criteria (on trade intensity), the threshold is 5%.

The carbon costs test provides a good indication of the impact of the carbon on the overall cost structure. Other approaches can be tried (e.g. costs over margins, or over EBIDTA). It is however clearer, more relevant and easier to understand than other financial-type tests used in other jurisdictions (e.g. carbon intensity over revenue). While other risk factors in the carbon-cost risk category are not captured with this test (e.g. abatement potential and the cost of abatement), there is a sense that carbon costs provide credible coverage (MARCU et al., 2014).

There are significant approximations associated with this carbon-cost risk test. An European Union Allowance (EUA) price forecast (€30/tonne) is used, which is being criticised for being far above the current (and forecast to 2020) market price. However, it must be considered that €30/tonne is a price that is put forward for an investment decision time frame, as the CLL addresses all channels of carbon leakage, including investment. From this point of view, a long-term price of €30/tonne cannot be seen as unrealistic, and could in fact be considered conservative. However, this needs to be specified and clarified in the Directive itself.

4.2.1.1.2. Trade Intensity (TI)

Articles 10a, Pars 15 and 16 define the trade intensity criterion as “the intensity of trade with third countries, defined as the ratio between the total value of exports to third countries plus the value of imports from third countries and the total market size for the Community (annual turnover plus total imports from third countries)" (EUROPEAN PARLIAMENT and EUROPEAN COUNCIL, 2009). In formula, this would yield:

$$TI = \frac{Imports+Exports}{Production+Imports} \quad \text{(Equation 2)}$$

Sectors are considered to be exposed to carbon leakage risk if trade intensity is over 30% (as a stand-alone). A 10% threshold is used if the trade intensity test is combined with another test (carbon cost).

So the ability to pass through additional costs from carbon pricing is captured with the surrogate test on trade intensity. While this clearly captures heavily-traded products, it does not capture all risk factors associated with pass-through ability, such as price setting power and market concentration (MARCU et al., 2014).

However, this definition, although more clear than the additional carbon cost criterion, still lacks a proper definition of the concept of 'third countries'. During the comitology process, without much discussion, third countries were defined as extra-EU 27 (all the countries that are not part of the EU 27) (BRUYN, NELISSEN and KOOPMAN, 2013b). However, this is not a logical definition in the context of EU ETS, as the EU ETS is larger than the EU 27 and includes installations from Norway, Iceland, Croatia, and Liechtenstein and planned linkages with Switzerland and Australia.

The trade intensity criterion was established in the light of the discussion of potential carbon leakage. Therefore, the concept of third countries should be: 'countries not included in the EU ETS'. Also the planned linkage with other ETS implies that prices will equalize on these markets, and one cannot speak about carbon leakage. As a result, all countries that are included in the ETS or linked to the ETS cannot be regarded as 'third countries' but are part of the ETS. According to BRUYN, NELISSEN and KOOPMAN (2013a), trade to those countries should not be included in the trade intensity criterion.

4.2.1.1.3. Results and Analysis

From the literature, as will be shown in this subsection, a total of 167 sectors, and in some cases sub-sectors, were added to the CLL based on the quantitative criteria, of which 10 meet more than one criterion: 24 sectors meet criterion 1., 6 meet criterion 2., while 147 sectors meet criterion 3. 6 sectors were added based on the qualitative criteria (ZAKLAN and BAUER, 2015).

The emerging evidence from the EU ETS suggests that, on the one hand, such free allocation provisions have been successful in preventing carbon leakage (BRANGER and QUIRION, 2013; SARTOR, 2012; COSTANTINI and MAZZANTI, 2012; QUIRION, 2011; ELLERMAN, CONVERY and DE PERTHUIS, 2010; REINAUD, 2008; LACOMBE, 2008).

On the other hand, there is concern that excess free allocation has lead to over-compensation of sectors. During the first and second trading periods (2005–2007 and 2008–2012), billions of euros of windfall profits were accrued by heavy emitters who passed through the opportunity cost of allowances they received for free (MAXWELL, 2011; BRUYN, NELISSEN and KOOPMAN, 2013a, b; LISE et al. 2010; MARTIN, MUÛLS and WAGNER, 2010). The issue of windfall profits not only reduces the credibility of the scheme, but analysis has also shown that excess free allowance allocation can have drawbacks for economic efficiency, for example by discouraging the closure of less efficient plants (HEPBURN et al., 2006; NEUHOFF, KEATS and SATO, 2006), and by dampening incentives for emissions reductions (ABRELL, FAYE and ZACHMANN, 2011) as well as innovation and low carbon investments (MARTIN et al. 2013).

The intention to progressively abandon free allocation in favour of auctioning was expressed by the European Commission under the revised ETS Directive (2009/29), and the free allocation provisions are subject to review at least every 5 years (SATO, 2015). In trading Phase III (2013-2020) allocations to installations in sectors not deemed to be at risk of carbon leakage are adjusted using an allocation factor such that they received 80% of their original gross allocation in 2013 for free, decreasing to 30% by 2020 (EUROPEAN PARLIAMENT and EUROPEAN COUNCIL, 2009). However, if a sector is on the CLL installations continue receiving 100% of the original gross allocation for free. The design of the provision for the period after 2020 is currently under discussion.

There are different views on the adequacy of the current two categories leakage risk in the EU. According to a stakeholder consultation by the EUROPEAN COMISSION (2014), 56% of industry respondents are in favor of maintaining the current system with two categories of leakage risk, whereas 21% believe that all sectors should be deemed at risk. Only 15% of respondents believe that more differentiation through additional leakage risk categories should be introduced. However, the empirical evidence suggests that parts of industry may be overcompensated at the current level of free allocation (HEILMEYR and BRADBURY, 2011). MARTIN et al. (2014) found that a large number of sectors benefited from receiving free allowances in excess of what would be required to neutralize the risk of carbon leakage.

In general, the outcome of the test for carbon leakage risk seems to be a very broad list, with almost everyone included. There are currently 167 sectors on the CLL, out of a total of 258 industrial sectors, covering approximately 95% of total industrial emissions in EU ETS (DE BRUYN, NELISSEN and KOOPMAN, 2013b).

The EU ETS has risk-mitigation provisions for those sectors found to be at risk, and thus included in the CLL. For direct emissions they receive free allocation (to the level of the benchmark) at the EU level, while compensation for indirect emissions is determined and awarded at the member state level (subject to EU state-aid rules) (MARCU et al., 2014). The amount of free allocation for sectors not on the CLL decreases until 2020, and it decreases at a higher rate than the free allocation for CLL sectors.

Therefore the EU ETS model can be described as ex-ante and fixed with allocation based on benchmark methodology for all sectors. It may lead to a significant amount of costs not being covered, depending on the sector's characteristics (spread around the benchmark). In addition, it does not compensate for any carbon costs related to increased production levels as it is based on historical levels of production and could be seen as not encouraging investment and/or increased production.

Table 13 lists the top 10 sectors with respect to their size of verified emissions (expressed as the average of 2005 and 2006 compared to the total verified emissions of industrial installations under the ETS for this sector) and the allocation decision of this sector.

Table 13 – Top 10 sectors and their allocation methods in 2013
Source: DE BRUYN, NELISSEN and KOOPMAN (2013a)

#	NACE 4	Short description	% of CO_2eq	Situation 2013 for allocation up to benchmark	Criteria
1	2320	Manufacture of refined petroleum	25%	Free	1
2	2651	Manufacure of cement	25%	Free	2
3	2710	Manufacture of basic iron and steel	14%	Free	1/3
4	2112	Manufacture of paper and paperboard	6%	Free	1
5	2652	Manufacture of lime	4%	Free	2
6	1110	Extraction of crude petroleum and natural gas	2%	Free	3
7	2414	Manufacture of other organic basic chemicals	2%	Free	1/3
8	2613	Manufacture of hollow glass	2%	Free	1
9	2310	Manufacture of coke oven products	1%	Free	1/3
10	1583	Manufacture of sugar	1%	Free	1

Note: Criteria 1. direct and indirect costs increase production costs by at least 5% of GVA and trade intensity is over 10%; criteria 2. direct and indirect costs increase production costs by at least 30%; and criteria 3. trade intensity is over 30%.

There are two main costs associated with the EU ETS carbon leakage risk mitigation measures. The first one is the administrative cost associated with setting up the system and the ongoing administrative burden. Both of them are not significant, according to RENDA et al. (2013a,b). The second cost category relates to the opportunity cost of free allowances, which decrease auctioning revenue. While a purely political consideration, it must still be acknowledged.

Finally, data acquisition and provision in the EU ETS in general, and in addressing carbon leakage in particular, are problematic. As discussed above, data on the information to address carbon leakage are aggregated according to NACE 4 or 6 – which represents the level of aggregation of the European Union economic activity –, while emissions data are aggregated by sectors that have a different definition (ZAKLAN and BAUER, 2015). This constitutes a real barrier to cross-referencing and analysing the impacts of financial and emissions information.

4.2.1.2. California Cap-and-Trade

One way of addressing overcompensation of some sectors while maintaining the CLL mechanism may be to differentiate the levels of leakage risk into more than the two categories currently used in the EU ETS. The Californian Cap-and-Trade system provides an example of greater differentiation.

This system uses only quantitative risk tests to determine if sectors are at risk of carbon leakage (CARB, 2006). The test used is a combination of emissions intensity and trade intensity. This combined test covers both risk factors – carbon costs and ability to pass through, and it leads to a division of installations into three carbon leakage risk categories: high, medium or low, as can be seen in Table 14.

Table 14 – Emissions Intensity, Trade Exposure and Leakage Risk in the California Cap-and-Trade

Source: Adapted from California Air Resource Board – CARB (2006, 2012)

Carbon Leakage Risk	Emissions Intensity	Trade Intensity
High	High	High
		Medium
		Low
	Medium	High
Medium	Medium	Medium
		Low
	Low	High
		Medium
Low	Low	Low
	Very Low	High
		Medium
		Low

Note: The number in between brackets states the total number

This analysis can also be explained by the following matrix (Figure 21), which represents the relation between emissions intensity and trade intensity to define the carbon leakage risk.

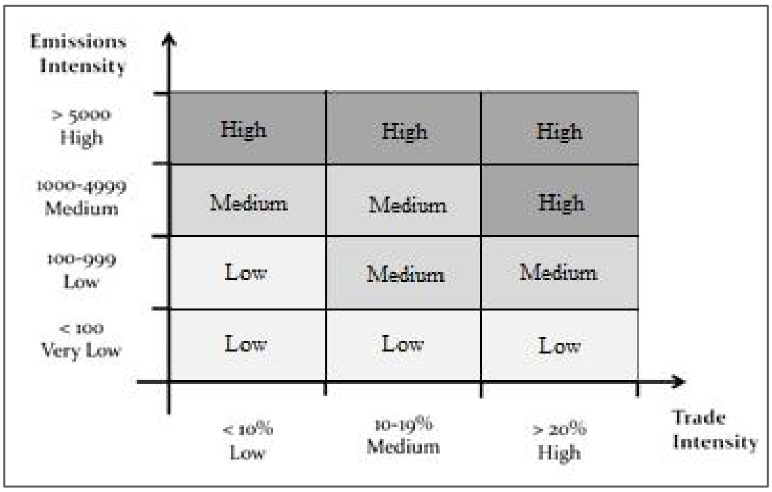


Figure 21 – Californian Assessment of Carbon Leakage Risk

Source: Adapted from CARB (2006, 2012)

All sectors are classified as low, medium or high, and there is no "no risk" category. This tiered approach provides a flexible way of recognising that carbon leakage risk is almost impossible to define with precision (MARCU et al., 2014).

4.2.1.2.1. Emissions Intensity (EI)

With respect to the impact of carbon costs, emissions intensity was chosen in order to avoid using carbon price forecasts (CARB, 2012). As in the case of Australia – that will be analyzed in the next subsection –, one could argue that this is a less representative way to capture risk factors related to carbon costs. It captures the importance of GHG emissions, but not, at least not to the same extent, the weight of carbon costs relative to the cost of production or sectorial margins.

$$EI = \frac{Tonnes\ CO_2e}{Million\ USD\ Value\ Added} \qquad \text{(Equation 3)}$$

This risk test is not used alone, but in conjunction with trade intensity (discussed below).

4.2.1.2.2. Trade Intensity (TI)

The ability to pass through additional costs from carbon pricing is captured through the trade-intensity test. California has a similar approach to the EU, but trade exposure is categorized, as mentioned before, as low, medium and high risk. The trade intensity (TI) test is calculated as follows:

$$TI = \frac{Imports+Exports}{Shipments+Imports} \quad \text{(Equation 4)}$$

This approach provides some information regarding the sectors' ability to pass through costs, but many aspects are not covered. In contrast to other jurisdictions, there are no qualitative tests that would inject some flexibility and which could be useful to provide more information on the ability of the sector to pass costs through.

4.2.1.2.3. Results and Analysis

According to the literature, none of the tests is used on a stand-alone basis, which is usually used to capture outliers. The California risk-based approach reduces (possibly eliminates) the need to cover for outliers, as every sector is covered in some way. This risk-based approach seems to assign a higher value to emissions intensity compared to trade intensity (MARCU et al., 2014).

There are two types of output-based allocation: product-based or energy-based (CALIFORNIA CODE OF REGULATIONS, 2011). Product-based benchmarks are preferred since it can recognize early action and enhance leakage protection. In some sectors, however, benchmarks can be difficult to develop due to high variation among facilities for example. If so, energy-based benchmarks are applied.

The benchmarks are generally set at close to 90% of average sectorial emissions or energy consumption. Initially all sectors received allowances at 100% of the benchmark, but while high-risk industries do not experience a decrease in free allocation, those at medium and low risk do (up to respectively 50% and 30% of the benchmark in 2020) (MARCU et al., 2014).

In the California Cap-and-Trade system, Industry Assistance Factor (IAF) is different over three initial compliance periods and over high, medium and low leakage risk industries. As mentioned, allocation is determined via a sector-specific intensity benchmark and is output-based. Initially the benchmarks are set at about 90% of average emissions. Free allocation is declining over time (CALIFORNIA CODE OF REGULATIONS, 2011).

According to MARCU et al. (2014), the Allowance Price Containment Reserve (APCR) receives allowances every budget year and holds auction every quarter at pre-established prices. In budget years 2013 and 2014, 1% of the total number of allowances enters the APCR, 4% for budget years 2015-17 and 7% for budget years 2018-20. The allowances in the APCR are split into three equal segments. These three segments are made available for auction with respective price levels of $40, $45 and $50 (2013). These prices increase yearly by 5% plus inflation. The APCR is linked to a floor price ($10 in 2012, increasing yearly): allowances that remain unsold at government auctions (because the value of the allowance is deemed less than the floor price) enter the APCR.

Tables 15 and 16 present the emissions and trade intensity for sectors in California, respectively.

Table 15 – Emissions intensity of selected sectors in California (tonnes CO_2eq/$ million value added)

Source: Adapted from California Air Resource Board (2006)

Emissions-intensity classification	Sector	Emissions Intensity
High	Lime manufacturing	29,398
(2)	Cement manufacturing	13,744
Medium	Iron and steel mill	4,148
(12)	All other basic inorganic chemical manufacturing	2,636
Low	Steel and aluminium processing	645
(7)	Pesticide and other agricultural chemical mfg	232
Very Low	Pharmaceutical and medicine manufacturing	64
(3)	Aircraft manufacturing	37

Note: The number in between brackets states the total number of sectors in that classification

Table 16 – Trade intensities of selected sectors in California (%)

Source: Adapted from California Air Resource Board (2006)

Trade-intensity classification	Sector	Trade share
High, > 19% (2)	Oil and gas extraction	65%
	Aircraft manufacturing	61%
	Flat glass manufacturing	46%
	Steel and aluminium processing	37%
	Pestice and other agricultural chemical manufacturing	20%
Medium, 10-19% (12)	Cement manufacturing	16%
	Petroleum products manufacturing	13%
Low, < 10% (7)	Lime manufacturing	3%

Note: The number in between brackets states the total number of sectors in that classification

This classification system achieves some differentiation of leakage risk, classifying 15 sectors in the high risk category, 14 as medium risk, and 3 as low risk (MARCU et al., 2014). Similar to the EU ETS, allocation factors depending on the overall risk level adjust the amount allocated for free. Installations in high-risk sectors receive 100% of their allocation for free during the entire period 2013-2020, while the allocation sinks from 100% in 2013-2014 to 75% in 2015-2017 and 50% in 2018-2020 for the medium category. Free allocation sinks even faster in the low-risk group, from 100% in 2013-2014 to 50% in 2015-2017 and 30% in 2018-2020 (CALIFORNIA CODE OF REGULATIONS, 2011).

In the Californian Cap-and-Trade system, differentiating according to leakage risk leads to a greater number of allowances available for auctioning (ZAKLAN and BAUER, 2015). Also, it is a sub-national scheme and therefore its impact on international negotiations is perhaps limited. But as a member of the Western Climate Initiative (WCI) and more specifically through the link with the Quebec ETS it is showcasing how carbon-pricing mechanisms could work together. It is too soon, however, to evaluate the full link between California and Quebec as it only entered action at the start of 2014.

4.2.1.3. Australian Carbon Pricing Mechanism (ACPM)

Australia has both quantitative and qualitative carbon leakage risk tests. The quantitative test is a combination of trade exposure (for ability to pass through) and emissions intensity (carbon-related).

Sectors that do not pass the trade-intensity threshold can submit an application for a qualitative assessment in Australia. If the activity does not reach the trade-intensity threshold, there is a complementary qualitative test to determine pass-through ability. The basis for the qualitative assessments are described and justified for each activity that is eligible, which makes the Australian system flexible and transparent, and covers many of the risk factors associated with pass-through ability.

4.2.1.3.1. Emissions Intensity in Revenues (EIR) and Emissions Intensity in Value Added (EIVA)

In Australia, emissions intensity is divided into three levels: high, medium and not emissions-intensive (DECCEE, 2011a, 2012).

- Highly emissions-intensive: at least 2,000 tCO_2eq emissions per million Australian dollar (AUD) revenue or 6,000 tCO_2eq per million AUD value added;
- Moderately emissions-intensive: 1,0000 tCO_2e emissions per million AUD revenue or 3,0000 tCO_2eq per million AUD value added.

$$EIR = \frac{Tonnes\ CO_2eq}{Million\ AUD\ revenue} \qquad \text{(Equation 5)}$$

$$EIVA = \frac{Tonnes\ CO_2eq}{Million\ AUD\ Value\ Added} \qquad \text{(Equation 6)}$$

Prior to testing for emissions intensity, a trade intensity test is used to assess if the activity is trade exposed. If the emissions intensity is below the trade intensity threshold, the activity is not eligible (DECCEE, 2012).

With respect to carbon-related risk tests, the Australian emissions intensity approach is less direct than the carbon costs test, which is used in the EU ETS. It gives a measure of carbon intensity but does not cover carbon-related risk factors to the same extent.

Intuitively, thresholds for emissions intensity over revenue and value added are not easy to capture. The thresholds are absolute numbers and as such are difficult to interpret. For example, the thresholds for highly emissions-intensive activities is 2,000 tonnes CO_2eq over 1 million AUD of revenue, or 6,000 tonnes CO_2eq over 1 million AUD of value added. As an observer, it is difficult to value the relevance of these thresholds.

As a plus, emissions intensity uses historical data on emissions, and as such does not rely on carbon price forecasts the way the EU ETS does. The emissions-intensity test is flexible in the way that it recognizes different levels of risk. The graduated structure and its link to the level of assistance are also clear and straightforward.

4.2.1.3.2. Trade Intensity (TI)

Trade intensity is used as a proxy to test for the ability to pass-through carbon costs. This quantitative test captures heavily traded products, but not all risk factors associated with pass-through ability. Moreover, the trade intensity criterion in Australia is calculated as imports and exports over domestic production, i.e. not over the sum of domestic production and imports (as in the EU and in California). This means that trade share could be overstated for activities with high levels of import. This risk test on trade intensity does not provide a threshold for outliers.

$$TI = \frac{Annual\ Value\ of\ Imports + Annual\ Value\ of\ Exports}{Annual\ Value\ of\ Production} \quad \text{(Equation 7)}$$

A slight variation regarding EU ETS was employed in the Australian ETS where trade intensity is calculated as a ratio over domestic production. If the ratio is higher than 10% in any of the financial years 2004-05, 2005-06 or 2007-08, the sector is considered to be trade exposed (DECCEE, 2011a,b). This is then combined with a test on emissions intensity in order to determine the level of compensation.

For those activities that meet the threshold of 10% trade exposure, the risk exposure is determined through emissions intensity thresholds (highly emissions-intensive activities and moderately emissions-intensive), creating a number of levels of compensation. Eligible emissions include direct emissions and electricity emissions (DECCEE, 2011b).

So the trade exposure test is a quantitative in/out test and can, under certain circumstances, be complemented with a qualitative test (if there is a demonstrated lack of capacity to pass through costs).

4.2.1.3.3. Results and Analysis

Currently, 35 activities on the list are highly emissions-intense and 16 sectors are moderately emissions-intensive (MARCU et al., 2014). Table 17 illustrates a selection of activities in Australia and their emissions intensity.

Table 17 – Emissions intensity of selected sectors in Australia (tonnes CO_2eq/$ million revenue)

Source: Adapted from DECCEE (2012)

Activity	Emissions intensity	Emissions intensity classification
Production of clinker	15,600-15,699	H
Production of lime	12,100-12,199	H
Aluminium smelting	5,700-5,799	H
Integrated iron and steel manufacturing	3,200-3,299	H
Production of bulk flas glass	2,100-2,199	H
Production of ceramic floor and wall tiles	1,100-1,199	M

Note: H = High emissions intensive; M = Moderately emissions intenstive.

Four sectors in Australia qualified through the qualitative assessment. This qualitative test is meant to assess whether there is a demonstrated lack of capacity to pass through costs due to international competition. Such lack can be demonstrated using one of the following:

- historical trade shares above 10%;
- high correlation between the prices received by domestic producers and a transparent international price; or

- existence of international producers who trade in the product that is a substitute for the domestically produced good.

Regarding the coverage of the eligible activities in Australia, the study by SFS Economics (2011), concluded that all but one of the eligible activities in Australia would qualify for the EU CLL, while 126 of the EU ETS sectors (from the original CLL in 2009) would not receive assistance in Australia. This study also compares the economic implications of the risk tests in Australia with the situation in EU. While the sectors in the EU ETS that are on the CLL cover 42% of employment, the corresponding figure for eligible activities in Australia is 9%. For turnover, the EU CLL covers 48%, while the number in Australia is 29%. As such, the risk tests in Australia seem to be more focused than in the EU – the study concludes with an appeal for broader Australian coverage.

The Australian risk identification focuses on “manufacturing activities”, whose definition, in general, is similar to the sector definitions used in the EU and California, but not for all sectors (MARCU et al., 2014). For example, the different segments of the steel and paper/pulp sectors are kept separate in the EU while in Australia, the value chains, starting from raw material processing, are kept together when assessing leakage and providing compensation.

Under the Australian Jobs and Competitiveness Programme, activities that demonstrated the potential to meet the carbon leakage criteria were initially assessed. The plan was to update the assessment in the third year of operation of the CPM (2014-15) and thereafter, at regular intervals (DECCEE, 2011b). Firms could also petition the Government to assess the carbon leakage risk of their activity.

Australia uses free allocation as risk mitigation under the Jobs and Competitiveness Program. If the activity passes the trade exposure criteria, free allocation is provided in a graduated manner, based on the activities’ emissions intensity. Free allocation in Australia is done ex-ante, and based on the entity’s previous year’s level of production, with a true up to account for actual production in the previous period.

Moderately emissions-intensive activities receive 66% free allocation and highly emissions-intensive activities receive 94.5% free allocation. Allocation for both categories declines by 1.3% per year (DECCEE, 2011a).

The existing provisions cover direct emissions and indirect emissions from electricity use. Also, ensuring that the playing field remains level for importers and exporters can be considered as addressed, as the trade-exposure test includes both imports and exports.

The risk-based allocation in Australia is flexible as it addresses leakage risk differences between sectors in a more realistic way than an "in/out" approach (MARCU et al., 2014). Besides, with respect to market functioning, according to estimates by the Department of Climate Change and Energy Efficiency in Australia, around 63.5% of the permits would be offered in the first auctioning, while 28% are allocated to emission-intensive, trade-exposed (EITE) activities (BETZ et al., 2010). As such, it does not seem that free allocation could hinder the good functioning of the carbon market.

4.2.1.4. Assessment and Comparison of Methodologies

From the methodologies discussed, two main risk tests are used: carbon-related risk test and trade-related risk tests. Carbon-related risk tests check for the impact of carbon cost, or carbon emissions, relative to a measure of financial performance. Currently two approaches can be identified:

- Emissions intensity: carbon emissions intensity (tonnes) relative to revenue (monetary value); and
- Carbon costs: impact of carbon costs (monetary value) relative to gross value added (monetary value).

Emissions intensity tests are currently used in California and Australia and can be looked upon, in a more general way, as an indicator of carbon intensity relative to financial performance. This could also be extrapolated to the carbon intensity of GDP. While emissions-intensity tests can be seen as less targeted than carbon cost tests, it remains a relationship between emissions intensity of an installation and its compliance costs.

For these tests, the approach used is that emissions intensity thresholds are defined, which then determine the risk level. It must be emphasised that the data used for these tests are historical, not a forecast.

Carbon costs relative to value added, is the second approach, currently used in the EU, and which was also included in the proposed Waxman Markey Bill (American Clean Energy and Security Act), approved by the US House of Representatives in June 2009 but defeated by the Senate in the US. This test is currently used as a stand-alone, or in combination with another test.

Regarding trade-related risk tests, trade intensity or trade exposure takes different forms depending on the jurisdictions. They examine whether or not the sector can pass the additional carbon cost to downstream consumers by raising sale prices. Table 18 summarizes the indicators and thresholds.

Table 18 – Comparison between quantitative risk test

Source: Own elaboration based on EUROPEAN COMISSION (2014), EUROPEAN PARLIAMENT AND COUNCIL (2009), CARB (2012), CALIFORNIA CODE OF REGULATIONS (2011), DECCEE (2011a,b, 2012)

Jurisdiction	Quantitative Indicators	Thresholds determining exposure to carbon leakage	
		Stand-alone test	Combined tests
EU ETS	$Carbon\ Cost(CC) = \frac{Direct\ Emissions\ tCO_2 + Indirect\ Emissions\ tCO_2) * Carbon\ Price/tCO_2}{Gross\ Value\ Added}$ $Trade\ Intensity\ (TI) = \frac{Imports + Exports}{Production + Imports}$	CC > 30% **or** TI > 30%	CC > 5% **and** TI > 10%
California Cap-and-Trade	$Emissions\ Intensity\ (EI) = \frac{Tonnes\ CO_2eq}{Million\ USD\ Value\ Added}$ $Trade\ Intensity\ (TI) = \frac{Imports + Exports}{Shipments + Imports}$	-	Emissions Intensity (EI) • High > 5,000 • Medium: 1,000-4,999 • Low: 100-999 • Very low: less than 100 **and** Trade Intensity (TI) • High > 19% • Medium: 10%-19% • Low: less than 10%

Australian Carbon Pricing Mechanism (ACPM)	$Emissions\ Intensity\ in\ Revenues\ (EIR) = \frac{Tonnes\ CO_2 eq}{Million\ AUD\ Revenue}$ $Emissions\ Intensity\ in\ Value\ Added\ (EIVA) = \frac{Tonnes\ CO_2 eq}{Million\ AUD\ Value\ Added}$ $Trade\ Intensity\ (TI) = \frac{Annual\ Value\ of\ Imports + Annual\ Value\ of\ Exports}{Annual\ Value\ of\ Production}$	-	First tier TI > 10% **and** EIR > 2,000/AUDm **or** EIVA > 6,000 tCO_2eq/AUDm Second tier TI > 10% **and** 1,000 < EIR < 2,000 tCO_2eq/AUDm **or** 3,000 < EIVA < 6,000 tCO_2eq/AUDm

4.2.2. Evaluation of Impacts on the Brazilian Industry

This section focuses on applying quantitative indicators of industrial vulnerability from the CPI implementation, considering the methodologies presented in the previous section. These indicators were built from the primary data from public institutions, such as the Ministry of Mines and Energy (MME); Ministry of Science, Technology and Innovation (MCTI); Ministry of Finance (MF); Ministry of Development, Industry and Commerce (MDIC); the Brazilian Institute of Geography and Statistics (IBGE); the National Development Bank (BNDES); and National Industry Confederation (CNI), among others (MME, 2017; MCTI, 2016, 2015; MF, 2014; MDIC, 2013; VIDAL and HORA, 2012;CGEE, 2014; BASTOS and COSTA, 2011; ABM, 2009). Some of them were already presented in chapter 3, especially concerning the economic characterization and the sectorial emissions profile. When related to international experiences, other sources were also used (HEEDE, 2014; CARBO, 2011; IEA GHG, 2000), as detailed in the following subsections.

The main objective of this section is to apply the indicators presented in the previous subsection to the Brazilian industry aiming at comparing the sectorial carbon leakage exposure. By using the different methodologies analyzed (EU ETS, California Cap-and-Trade and Australian CPM), we will assess which sectors are more vulnerable (or not) to this risk. From the previous subsection, the indicators used are emission intensity (EI), carbon cost (CC), and trade intensity (TI). These results will be used in the next chapter, considering not only these quantitative analyses, but also the qualitative ones carried out in the beginning of this chapter, aiming at proposing institutional frameworks for CPI in the Brazilian industry. Thus, in terms of section structure, initially, those indicators will be calculated at the subsectorial level. Subsequently, a comparative table will summarize the carbon leakage risk by each industrial subsector considering the three different methodologies.

4.2.2.1. Emissions Intensity

The average emission intensity (sectorial or by product), or an index based on the most efficient companies, can be adopted as benchmark for establishing a CPI, as seen in the previous section. This benchmark can provide incentives for preventive actions and long-term efficiency gains, but the method can be data-intensive, especially in the absence of large data series. Thus, international benchmarks can be useful when public data is available, providing the analyst (regulator) with the information needed. Furthermore, most Brazilian industrial processes are based on mature processes following consolidated international technological portfolios. As such, the position of the Brazilian industry in terms of emissions intensity can provide relevant information about the vulnerability of the industrial sectors to a possible carbon pricing (SANTOS et al., 2018).

Due to these reasons, this thesis analyzes emissions intensity under two different approaches: the first one is product-based, aiming at comparing the global and the national averages for emissions intensity, in metric tonnes of CO_2 per tonnes of product; the second one is emission-based, focusing on carbon emissions intensity (tonnes) relative to revenue (monetary value).

Concerning (inter)national emissions intensity, data were collected from the international literature (HEEDE, 2014; CARBO, 2011; IEA GHG, 2000) for the global average emissions intensity, while, for the Brazilian average emissions intensity, it was retrieved from the Ministry of Mines and Energy, Ministry of Science, Technology and Innovation (MCTI), National Development Bank (BNDES), as well as on some other sectorial industry reports (MME, 2017; MCTI, 2016, 2015; MF, 2014; MDIC, 2013; VIDAL and HORA, 2012; CGEE, 2014; BASTOS and COSTA, 2011; ABM, 2009). Table 19 shows the comparison between global and the Brazilian averages on emissions intensity, in metric tonnes of CO_2 per tonnes of product.

Table 19 – Emissions intensity – global average and Brazilian average – year 2005 (in tCO_2/t product)

Source: References for global average: HEEDE, 2014; CARBO, 2011; IEA GHG, 2000. References for Brazilian average: MME, 2017; MCTI, 2016, 2015; MF, 2014; MDIC, 2013; VIDAL and HORA, 2012; CGEE, 2014; BASTOS & COSTA, 2011; ABM, 2009

Subsector	Global Average	Brazilian Average
Aluminum	9.1 - 9.6	5.6
Cement, Lime and Glass	0.6 - 0.8	0.7
Pig Iron and Steel	1.6 - 2.2	1.3
Pulp and Paper	0.8 - 0.9	0.2
Chemicals	n.a.	0.3

Note: n.a. – not available

Although the average values may show a large spread due to the different structures and processes, a national (or international) average can serve as a benchmark for comparing the country's exposure to a carbon price, assuming a similar worldwide policy. For instance, when compared to the global average, the Brazilian Pulp and Paper sector shows lower emissions intensity (0.2 versus 0.8-0.9), and the same happens to the Aluminum sector (5.6 versus 9.1-9.6). Other sectors show average emissions intensity closer to the global average. For instance, Pig Iron and Steel (1.3 versus 1.6-2.2) and Cement, Lime and Glass (0.7 versus 0.6-0.8). The average emissions intensity of Chemicals is low (0.3) in Brazil, but there was not any information found for the global average due to the sector heterogeneity.

Thus, it can be concluded that defining a metric for carbon pricing based on international benchmarks could not provide incentive to lower Brazil's sectorial emissions. Moreover, the Brazilian industry is not homogeneous, especially regarding technology. Therefore, a national benchmark based on the most efficient plants could provide a better metric than an international benchmark. The difficulty relies on obtaining historical data. For some sectors, studies are not available, and research is required to establish national benchmarks (MDIC, 2013).

The second emissions intensity analysis focuses on carbon emissions intensity relative to revenue, indicating the ratio of sectorial emissions over the VA, as shown in Equation 8 below.

$$\text{Emissions Intensity}_{\text{i}}[\frac{\text{tCO}_2}{\text{US\$ millions}}] = \frac{\text{Emissions}_{\text{i}}\ [\text{tCO}_2]}{\text{Sectorial VA}_{\text{i}}\ [\text{US\$ millions}]} \quad \text{(Equation 8)}$$

Note: *i* = industrial subsector.

The results represent how much the carbon pricing could impact the return on the production factors (capital, labor) of these industries – under the conservative assumption that the sector does not abate any emissions. Table 20 presents the results for sectorial emissions intensity, in tCO_2/US$ millions.

Table 20 – Sectorial emissions intensity – year 2010 (in tCO_2/US$ millions)
Source: Own elaboration based on IBGE (2015) and MCTI (2015)

Subsector	Emissions (tCO_2) [A]	Sectorial VA (US$ millions) [B]	Emissions / VA (tCO_2/US$ millions) [C] = [A]/[B]
Aluminum	7,410,000	5,010	1,479
Cement, Lime and Glass	45,548,000	10,487	4,343
Pig Iron and Steel	45,531,000	7,945	5,708
Pulp and Paper	5,747,000	7,196	799
Chemicals	17,438,000	23,519	741

According to the results, the Pulp and Paper and Chemical sectors have the lower emissions intensity (under 1,000 tCO_2/US$ millions), especially because of the use of biomass in the Pulp and Paper sector, besides the high VA of the Chemical sector. On the other hands, Pig Iron and Steel, and Cement, Lime and Glass sectors have the biggest emissions intensity since both sectors are strongly energy intensive.

4.2.2.2. Carbon Cost

The estimated impacts of the cost of carbon pricing on the VA express the relative weight of the cost of carbon on the rents of the production factors, namely, capital and labor. It is given by the ratio of the carbon cost to VA and it will be calculated for different carbon prices (US$10/$tCO_2$, US$25/tCO_2, and US$50/$tCO_2$), reflecting a range typically found in the literature and in the carbon pricing international experiences put in place so far (ICAP, 2018; ALDY, 2016; CLARKE et al., 2014; NORDHAUS, 2007; STERN, 2007).

The carbon cost to VA considers full emissions of the year 2010 and, thus, it is a conservative indicator that assumes that the cost is fully absorbed by the industry, i.e., without considering any mitigation measures. For the calculation of the carbon cost, primary data from the sectorial emissions reported in the Third National Communication (MCTI, 2016) and the VA reported by the Brazilian Institute of Geography and Statistics (IBGE, 2015), expressed in US$ millions for the year 2010, is considered.

Figure 19 presents the impact of the cost of carbon pricing on the VA, given by the ratio of total tax expenditure to VA for different carbon prices (US$10/t$CO_2$, US$25/tCO_2, and US$50/t$CO_2$).

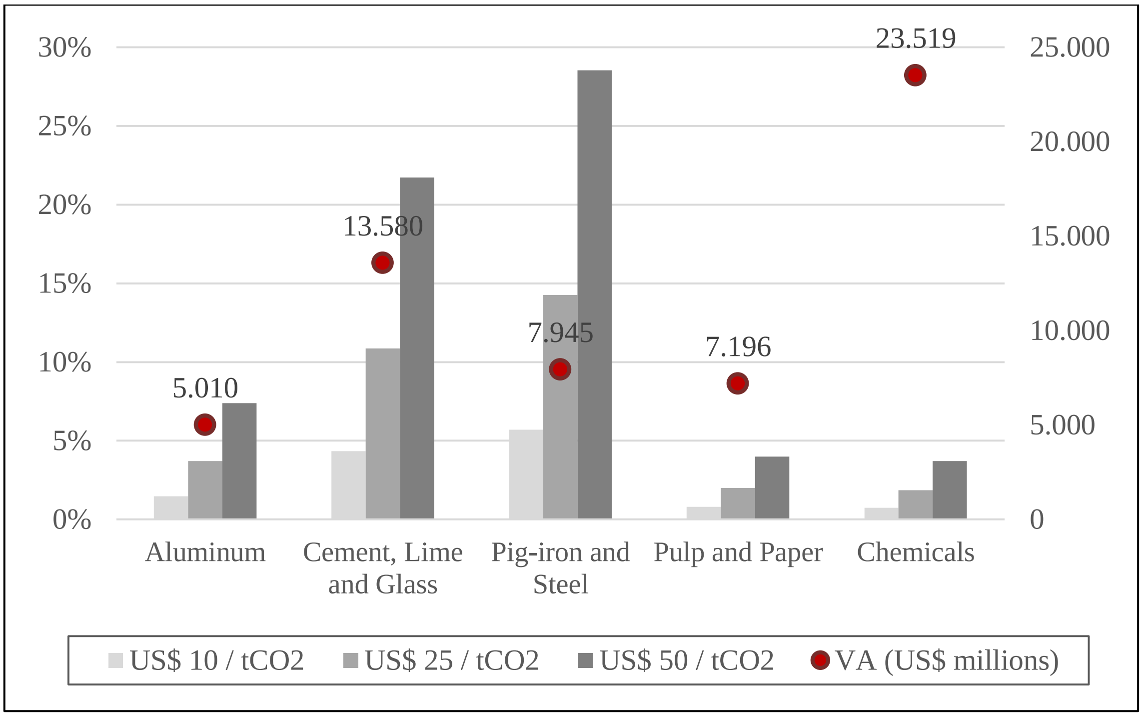


Figure 22 – Carbon cost in relation to the sectorial VA according to carbon prices (%) and sectorial VA (US$ millions) – 2010

Source: Own elaboration based on MCTI (2016) and IBGE (2015)

The results represent the cost of carbon in relation to the sectorial VA, i.e., how much the carbon pricing could impact the return on the production factors (capital, labor) of these industries, under the conservative assumption that the sector does not abate any emissions. For all sectors, the impact of a carbon price of US$10/t$CO_2$ would be less than 6% of the sectorial VA and would be less than 15% for values up to US$25/t$CO_2$. Pulp and Paper and Chemicals would not face high impacts of carbon pricing even for a carbon price of US$50/t$CO_2$, respectively 4% and 3.7%.

Another possibility of interpreting the impacts on the VA is to simulate a carbon price according to different levels of reduction in absolute emissions. This alternative analysis shows the effects (in terms of % of the VA) of internalizing a carbon price for the year 2010. The priced emissions are the total emissions minus the reduction of emissions varying from 0% to 45%. This range roughly expresses the abatement potentials found in the study led by the Ministry of Science, Technology and Innovation (MCTI, 2016) and covers the abatement of emissions needed to reach Brazil's NDC targets (37% and 43%). The indicator is calculated for different carbon prices, varying from US$10/t$CO_2$ to US$50/t$CO_2$. Table 21 shows the results.

Table 21 – Carbon Cost (%) according to carbon price (in US$ millions/tCO_2) and emissions reduction (% over total) – year 2010
Source: Own elaboration based on MCTI (2016) and IBGE (2015)

Subsector	Carbon price (US$/t$CO_2$)	% Reduction in sectorial emissions					
		0%	5%	15%	25%	35%	45%
Aluminum	10	1,5%	1,4%	1,3%	1,1%	1,0%	0,8%
	25	3,7%	3,5%	3,1%	2,8%	2,4%	2,0%
	50	7,4%	7,0%	6,3%	5,5%	4,8%	4,1%
Cement, Lime and Glass	10	4,3%	4,1%	3,7%	3,3%	2,8%	2,4%
	25	10,9%	10,3%	9,2%	8,1%	7,1%	6,0%
	50	21,7%	20,6%	18,5%	16,3%	14,1%	11,9%
Pig Iron and Steel	10	5,7%	5,4%	4,9%	4,3%	3,7%	3,1%
	25	14,3%	13,6%	12,1%	10,7%	9,3%	7,8%
	50	28,5%	27,1%	24,3%	21,4%	18,6%	15,7%
Pulp and Paper	10	0,8%	0,8%	0,7%	0,6%	0,5%	0,4%
	25	2,0%	1,9%	1,7%	1,5%	1,3%	1,1%
	50	4,0%	3,8%	3,4%	3,0%	2,6%	2,2%
Chemicals	10	0,7%	0,7%	0,6%	0,6%	0,5%	0,4%
	25	1,9%	1,8%	1,6%	1,4%	1,2%	1,0%
	50	3,7%	3,5%	3,2%	2,8%	2,4%	2,0%

Note: - impact + impact

For a carbon price of US$10/t$CO_2$, results show impacts below 5.4% for all sectors, with values ranging from 0.4% (Pulp and Paper, and Chemicals under a 45% emissions reduction scenario) to 5.4% (Pig Iron and Steel under a 5% emissions reduction scenario). These impacts grow for higher carbon prices and could reach 27.1% for Pig Iron and Steel under a 5% emissions reduction scenario with a US$50/t$CO_2$ carbon price. Pulp and Paper, and Chemicals showed the lowest impacts on the sectorial VA, even with higher carbon prices (US$50/t$CO_2$). For the former, this can be explained by the share of black-liquor in final energy consumption, while for the latter it derives from the higher VA of chemical industry facilities.

If the carbon price were fully internalized by the industry (e.g., via an ETS with auction or a carbon tax), the results presented in Table 21 would reveal an upper limit for the mitigation cost as a share of VA. In other words, the difference between the emissions reduction levels (5–45%) and the case with no emission reduction (0%) expresses the maximum cost of a carbon pricing (as a share of VA), assuming the respective level of mitigation. For instance, by mitigating 45% of the Pulp and Paper emissions, considering a carbon price of US$10/t$CO_2$, total expenditure of the sector would be 0.4% of its VA.

The range of reduction from 35% to 45% covers the same range of the NDC target (for the year 2025 and 2030) and could express the upper limits for the mitigation cost in a scenario where the NDC target is divided homogeneously between all the sectors in the economy (LULUCF, industry, etc.)[24]. Again, considering a carbon pricing of US$10/t$CO_2$, the cost of mitigation of reducing emissions from 35% to 45% could represent an impact of 0.3% to 2.6% on sectorial VA, depending on the sector assessed. Furthermore, considering a carbon price of US$10/t$CO_2$, and the reduction target of 5% (the same as the Industry Plan) (MDIC, 2013), the total sectorial expenditure would be under 0.7%.

4.2.2.3. Trade Intensity

The ability to pass-through compliance costs also depends on the sectorial exposure to international trade. Since trade is dynamic, technical difficulties arise when developing precise price metrics (OECD, 2016). Thus, the international experience relies on trade share metrics to measure the cost pass-through ability (CARB, 2012). Trade exposure is an indicator that expresses, through the export and trade shares, sectorial dependence on the international trade. It also represents trade intensity and the exposure of the sectorial production to international trade. Equations 9 and 10 show the export share and the trade intensity indicators, respectively.

$$\text{Export Share}_\text{i}[\%\text{X}_i] = \frac{\text{Exports}_\text{i}[\text{US\$}]}{\text{Exports}_\text{i}[\text{US\$}]+\text{Imports}_\text{i}[\text{US\$}]} \qquad \text{(Equation 9)}$$

[24] Certainly, this result is conservative, since it is unlikely to be cost-effective.

$$\text{Trade Intensity}_i[\%TI_i] = \frac{\text{Exports}_i[US\$]+\text{Imports}_i[US\$]}{\text{Gross Value Production}_i[US\$]} \quad \text{(Equation 10)}$$

The export share represents the sectorial export (or import) orientation, for which values above 50% indicate that a sector is export-oriented. The export share ($\%X_i$) indicator is equal to the sectorial exports (X_i) divided by the sum of sectorial imports (M_i) and exports (X_i). Similarly, the trade intensity expresses sectorial trade orientation, that is, how much the trade activity is relevant for the sector in relation to its gross value production (depending on the denominator). In this analysis, the trade intensity (TI_i) indicator is equal to the sum of X_i and M_i over the gross value of production (GVP_i), for which values above 50% represent propensity to trade.

Table 22 presents the results for the export share and the trade intensity for each subsector. According to the results, the Pulp and Paper subsector is export-oriented (76% of export share), while the Chemicals sector is import-oriented (import share varies from 14% to 31%, depending on the segment). Moreover, trade intensity is a metric that represents the exposure of the sectorial production to international trade – e.g., Cement, Lime and Glass sectors are less exposed to international trade (11%) while Aluminum is highly exposed (53%).

Table 22 – Sectorial export share and trade intensity – year 2010

Source: Own elaboration based on IBGE (2015)

Sectors	Gross Production Value - GVP_i (US$ millions)	Export - X_i (US$ millions)	Import - M_i (US$ millions)	Export Share ($\%X= X_i/(X_i+M_i)$)	Trade Intensity ($TI_i=(X_i+M_i)/GVP_i$)
Aluminum	22,359	7,170	4,761	60%	53%
Cement, Lime and Glass	30,092	1,731	1,679	51%	11%
Pig Iron and Steel	42,952	7,893	5,277	60%	31%
Pulp and Paper	26,387	5,608	1,751	76%	28%
Chemicals	95,443	9,570	32,225	14%-31%	28%-56%

4.2.2.4. Carbon Leakage Risk under Different Methodologies

After evaluating the impacts on the Brazilian industry considering the indicators used in the three methodologies presented in the previous section – emission intensity (EI), carbon cost (CC), and trade intensity (TI) –, this subsection aims to assess the risk of carbon leakage per subsector considering the different methodologies discussed (EU ETS, California Cap-and-Trade and Australian CPM). As a result, subsectors that are more vulnerable to this risk will be highlighted, assisting in the design of CPI that will take into account the mitigation of such impacts.

Table 18 summarizes the quantitative indicators and the thresholds that determine exposure to carbon leakage per methodologies, while Table 23 indicates the level of risk that each subsector would face. The importance of analyzing the risk of carbon leakage considering different methodologies is because their use results in different levels of risk per sector. For example, a sector can be considered as having a high risk of exposure to carbon leakage in a given methodology while presenting a medium risk in another. In this way, the main objective is to understand, from different approaches, which sectors are more risk-prone considering the different methodologies analyzed.

Table 23 – Carbon leakage risk comparison considering different methodologies

Source: Own elaboration

Subsector	Carbon Price (US$/$tCO_2$)	Emissions Intensity (tCO_2/US$ millions) [C] = [A]/[B]	Carbon Cost (%) according to carbon price (in US$ millions/tCO2)	Trade Intensity (Si = Xi + Mi/Yi)	EU ETS		California Cap-and-Trade			Australian CPM		
					Stand-alone test	Combined tests	EI	TI	Carbon Leakage Risk	EIVA[25]	TI	Carbon Leakage Risk
Aluminum	10	1,479	1,5%	53%	Risk	No risk	M	H	H	M	H	M
	25		3,7%		Risk	No risk						
	50		7,4%		Risk	Risk						
Cement, Lime and Glass	10	4,343	4,3%	11%	No risk	No risk	M	M	M	M	H	M
	25		10,9%		No risk	Risk						
	50		21,7%		No risk	Risk						
Pig Iron and Steel	10	5,708	5,7%	31%	Risk	Risk	H	H	H	M	H	M
	25		14,3%		Risk	Risk						
	50		28,5%		Risk	Risk						
Pulp and Paper	10	799	0,8%	28%	No risk	No risk	L	H	M	M	H	M
	25		2,0%		No risk	No risk						
	50		4,0%		No risk	No risk						
Chemicals	10	741	0,7%	28%-56%	Risk	No risk	L	H	M	M	H	M
	25		1,9%		Risk	No risk						
	50		3,7%		Risk	No risk						

Note: H: high; M: medium; L: low

[25] EIVA was chosen as the emission intensity indicator in the Australian CPM methodology aiming at comparing itself with the other two methodologies, since EIVA considers Value Added (VA) in its calculus.

From the use of different methodologies for assessing the risk of carbon leakage, an important conclusion emerges. The methodological definition for assigning the sectorial risk of exposure to carbon leakage into its different levels - no risk, low, medium and high, for example - is fundamental to the configuration of a CPI. Besides, there are several design features of risk tests that must also be taken into account when assessing risk criteria. As Table 23 shows, different results are found when using methodologies from EU ETS, California Cap-and-Trade and Australian CPM.

Among the three methodologies, the EU ETS is the only one in which the carbon leakage risk test employs an in/out approach. This means that a sector is either at risk or not at all, characterizing a certain inflexibility and rigidity of the methodology. Nevertheless, the revised ETS Directive outlines four criteria for defining if a sector or subsector is deemed to be exposed to a significant risk of carbon leakage. In case a sector would qualify for one of these, it would obtain free allocation of allowances (EUROPEAN PARLIAMENT and EUROPEAN COUNCIL, 2009), subjected to review at least every 5 years (SATO, 2015). Through these criteria, the methodology became more flexible.

As SFS Economics (2011) concludes while comparing EU ETS and Australian CPM, the risk tests in the latter seem to be more focused than in the former. All subsectors analyzed were considered as medium carbon leakage risk under the Australian CPM. Instead, considering the EU ETS methodology in the stand-alone test approach two subsectors were considered no-risk subsectors. They are Cement, Lime and Glass and Pulp and Paper. This is due to the fact that, for a sector to have a risk of carbon leakage in the stand-alone test approach, it is necessary that either the carbon cost or the trade intensity has to be higher than 30%, which ends up including many sectors in EU ETS Carbon Leakage List (CLL).

Still in the EU ETS methodology, but analyzing the combined test approach, under a US\$10/tCO_2 carbon price, only the Pig Iron and Steel subsector is considered at risk of carbon leakage. When the carbon price grows to US\$25/tCO_2, the Cement, Lime and Glass subsector became part of this list. Those subsectors considered under carbon leakage risk would receive an amount of free allowances, in case of an ETS implementation. Nevertheless, even under a US\$50/tCO_2 carbon price, Pulp and Paper, and Chemicals do not face carbon leakage risk, especially because of their lower emissions intensity. These results reinforce the feasibility of implementing a CPI in the industry sector.

Looking at the California Cap-and-Trade methodology, a different perspective comes to the table, because the exposure risk is leveled between low (L), medium (M) and high (H). In addition, another particular attribute is included in this methodology, due to the fact that none of the tests is used on a stand-alone basis. Thus, from the Californian approach, Aluminum and Pig Iron and Steel subsectors were classified as higher exposure to carbon leakage risk, while all the other subsectors were considered at a medium risk. No subsector was classified under low risk.

Comparing these outcomes with the EU ETS methodology, the same result is achieved from the stand-alone test, i.e., these sectors (Aluminum and Pig Iron and Steel) were considered at risk of carbon leakage no matter the price of carbon. When considering the combined tests, Pig Iron and Steel is still considered under risk, however the Aluminum sector is only considered from US\$50/tCO_2, besides Cement, Lime and Glass subsector is included from US\$25/tCO_2.

Similar to the EU ETS, in the California Cap-and-Trade, installations in high-risk sectors receive 100% of their allocation for free during a given period, while the allocation sinks from 100% in 2013-2014 to 75% in 2015-2017 and 50% in 2018-2020 for the medium category. Free allocation sinks even faster in the low-risk group, from 100% in 2013-2014 to 50% in 2015-2017 and 30% in 2018-2020 (CALIFORNIA CODE OF REGULATIONS, 2011). In the industrial Brazilian case, all subsectors would receive an amount of free allowances (in a ETS case)

A criticism can be made to the California Cap-and-Trade and Australian CPM methodologies. Both use absolute number thresholds for emissions intensity indicators, which are difficult to interpret. For example, the thresholds for highly emissions-intensive activities in the California Cap-and-Trade is 5,000 tonnes of CO_2eq per million USD value added, while in the Australian CPM it is 6,000 tonnes CO_2eq over 1 million AUD of value added. As a matter of fact, it is difficult to value the relevance of these thresholds, which can be considered a vulnerability (or even a weak point) of the methodology.

Finally, taking into account the specific results from the Australian CPM methodology, one can verify that all subsectors were considered under a medium carbon leakage risk, with no subsector classified as high or no risk. Under this mechanism, if the sector passes the trade exposure criteria, free allocation is provided in a graduated manner, based on the activities' emissions intensity. Considering this perspective, all industrial subsectors should receive free allocation, because they all were classified as under risk of trade exposure. Moderately emissions-intensive activities receive 66% free allocation in this methodology, declining by 1.3% per year (DECCEE, 2011a), so in the Brazilian industrial case all subsectors should receive this amount, because they all were classified as moderately emissions-intensive.

Summing up, it is possible to highlight some conclusions. Considering the three methodologies analyzed, all subsectors would face some carbon risk (medium to high), except the Pulp and Paper, in the specific case of using the EU ETS methodology. In all other scenarios, at least a medium carbon leakage exposure would become an expected but a not desired outcome of a CPI on the Brazilian industrial sector, as concluded by SANTOS et al. (2018). An average result would arise from using the Australian CPM methodology, when all subsectors would be classified as medium-risk. If the California Cap-and-Trade methodology is applied, all sectors are classified at least as medium-risk, being Aluminum and Pig Iron and Steel labeled as highly exposed.

5. Proposals of Institutional Frameworks for Carbon Pricing Instruments

This chapter aims to define and compare possible institutional arrangements for carbon pricing in the Brazilian industrial sector, in addition to proposing a particular arrangement that is believed to be more appropriate. To do so, besides making use of the information analyzed in the previous chapters, especially chapters 2, 3 and 4, it is also evaluated possible interactions between a pricing instrument in the industry with instruments in other sectors that relate directly (or indirectly) with the industry, being such sectors outside the scope of this thesis. Such specific analysis can be found in Annex C.

5.1. Defining Institutional Frameworks

It is possible to define a large and diverse number of possible CPI arrangements for the Brazilian industry. This section seeks to present some possibilities that have been identified as viable alternatives to implement a pricing instrument in this sector.

The definition of possible institutional arrangements contemplates the combination of the following elements: **type of price instrument** (carbon tax or ETS); **scope of emissions** (total or only process emissions); and **characterization of the instrument** (in the case of a carbon tax, the recycling ways, and, in the case of an ETS, the forms of allocation).

Some elements of analysis should be highlighted when comparing different combinations of institutional arrangements. First of all, although from a (microeconomic) theoretical point of view a tax and an ETS are equivalent, in practice the definition of the type of instrument can have a significant impact on the results in terms of emissions, economic effects on the sectors and cost of implementation (WORLD BANK et al., 2018; CPLC, 2016; CEBDS, 2016).

The result in terms of emissions depends, in the case of a carbon tax, on the reaction capacity of the industrial subsectors to the price signals and the ability to pass-through costs. In this case, it is difficult for the regulator to predict the final effect in terms of emission reductions due to information failures with respect to the costs of abatement of the agents. In the ETS case, emission reductions depend on the emission ceiling (cap) defined for the sectors, and its goal is guaranteed by the aggregate emission ceiling. However, also due to information failures, there is uncertainty in the trading price in an ETS. These uncertainties can have negative effects on the investment decisions of the agents, since there is no guarantee on the return on the abatement investment. Therefore, a carbon pricing instrument through taxation generates greater incentives for dynamic efficiency[26], although there is greater uncertainty regarding the amount of mitigation in the case of tribute versus market price uncertainties.

As discussed in chapter 2, elements such as transaction costs, flexibility and acceptability by agents should also be considered. ETS has transaction costs that need to be measured, especially in the absence of revenues from carbon pricing (free allowance). The market, however, is more flexible than taxation, allowing for easier adjustment of inflation and costs, entry of new agents, banking and borrowing and interaction with other sectors (offsets). Finally, the acceptance/rejection of the instrument should be considered, with the tax (or ETS with auctions) being less accepted by the agents due to the additional tax burden (SANTOS et al., 2018; PEREIRA and BERTHOLINI, 2017). Moreover, from direct dialogues with the Brazilian industry, it was possible to ascertain the repulsion that the sector, in general, presents against the introduction of more taxes, fact that will be better explored in section 5.2.

The second element to define the institutional arrangements for carbon pricing – emissions scope – influences the cost-effectiveness of the instrument and the interaction/necessity for complementary instruments. A pricing instrument will reduce emissions in a more cost effective manner as the number of participating sectors increases, allowing the use of mitigation options with lower abatement costs. A broader scope of emissions allows for a greater number of abatement options. Likewise, a broader scope (e.g. including energy emissions) reduces the need to formulate other specific instruments to deal with outside emissions of the original instrument scope.

Third, in the case of a carbon tax, the income allocation (recycling way) must be analyzed, in order to avoid the loss of purchasing power of the families and/or the loss of competitiveness of the industrial subsectors. In the case of ETS, one must consider the allowance allocation strategy (free or auction), which can, in turn, influence several aspects of this instrument. In this case, the main distinction is made between instruments that generate revenue for the regulator or not. In case the revenue generation exists, they can be recycled for a particular purpose. However, the payment leads companies to incur an additional burden of payment, when compared to the free allocation case, which makes difficult to implement the instrument.

[26] Dynamic efficiency refers to long-term incentives to reduce abatement costs based on the incentives provided by the pricing instrument.

As a result, two groups of alternatives are evaluated: carbon tax and ETS. Each group is subdivided by type of covered emissions (process or total). Finally, a third subdivision occurs regarding the characterization of the instrument: in the carbon tax case, two recycling options are evaluated, namely support to families and support to the industry, while in the ETS case, two allocation options are evaluated: for free or auction. Table 24 schematizes the analyzed alternatives.

Table 24 – Institutional Frameworks – Alternatives

Source: Own elaboration

Group	Covered Emissions	CPI Characterization	Arrangement Name
Carbon Tax (A)	Process Emissions (a)	Aimed at Families (1)	A.a.1.
		Industry Support (2)	A.a.2.
	Total Emissions (b)	Aimed at Families (1)	A.b.1.
		Industry Support (2)	A.b.2.
ETS (B)	Process Emissions (a)	Free Allocation (1)	B.a.1.
		Auction (2)	B.a.2.
	Total Emissions (b)	Free Allocation (1)	B.b.1.
		Auction (2)	B.b.2.

Finally, the evaluation of the proposed institutional arrangements will, in particular, consider the effects on purchasing power and competitiveness. In this way, the proposition of arrangements will try to seek as a key element of its formulation the attempt to minimize negative effects on these two aspects. In this sense, revenue recycling, when available, will play a key role in defining and implementing the CPI.

5.1.1. Group 1 – Carbon Tax

Among the tax typologies, discussed in section 3.4.3., a carbon tax would be better represented by a contribution, so that its recycling can be turned to a specific purpose. Therefore, if a possible "carbon tax" has a specific allocation to a carbon fund, for example, it should be treated as a "CIDE carbon" and not as a "carbon charge". Thus, the fiscal instrument could be configured as a "carbon tax" or as a "carbon contribution" - depending on the existence (or not) of the allocation in a predetermined fund - but never as a "carbon charge". It is recalled that the contributions differ from the charges, since their generating facts are not activities of the State. Nor can they be characterized as taxes, since they have a specific destination (GIAMBIAGI and ALÉM, 2000). The proposal, then, would be that of a contribution, given the specific allocation of revenue.

As far as the coverage of the tax is concerned, it can only refer to process emissions or total emissions. Certainly, this definition will have a strong impact on the CPI performance, since, according to the subsectorial emissions profile analyzed (section 3.3), some subsectors have very low process emissions - for example, Pulp and Paper. However, this same subsector have energy emissions almost 20 times higher than their process emissions, so the reality of the sector would change a lot in front of the introduction of a CPI that covered the total emissions.

Regarding the revenue recycling ways discussed in section 4.1.2.2., whose objective is to mitigate the impacts of the implementation of the CPI in Brazilian industry, it is concluded that the following three cases do not need to be analyzed: recycling aimed at reducing other taxes, the general government budget and investment in climate funds. In the first one, it is identified a great difficulty of implementation due to the need of a broad Tax Reform, a reform that is currently under discussion in the National Congress, but without major advances. In the second case, it is observed some difficulties concerning the return of the revenues derived from carbon-pricing, since such revenues could not be focused on reducing the loss of purchasing power and/or competitiveness given the fiscal constraints faced by Brazil. Therefore, these two recycling ways will not be considered, since the CPI is intended to ensure that such revenue is returned to actions aimed at climate change.

In addition, there is no justification for analyzing the case of investments in climate funds, since there is no guarantee that this revenue recycling alternative will mitigate the impact on the industry, nor the impact on households' purchasing power. Thus, in order to reverse the revenue for a predetermined purpose, a carbon tax would come in the form of a contribution. Also, in order to avoid the loss of purchasing power of families and/or the loss of competitiveness of companies, the proposals for recycling are: support to families and support to industry. The alternatives presented in Table 24 are described below.

5.1.1.1. Alternative A.a.1

This alternative shows a carbon tax in the form of a contribution, covering only process emissions, whose revenue is aimed at reducing the negative effects on households' purchasing power. Recycling can be done through direct transfers, reducing taxes on families, subsidies or assistance programs.

5.1.1.2. Alternative A.a.2

In this alternative, the carbon tax would be implemented as a contribution, covering only the process emissions, and its revenues would provide support to the industry, with a view to reducing the effects on competitiveness. The contribution can be recycled through financing for production and investment, tax credits, support for RD&I, or energy efficiency programs.

5.1.1.2. Alternative A.b.1

This alternative is equivalent to alternative A.a.1., but total emissions are considered, not just process emissions.

5.1.1.2. Alternative A.b.2

This alternative is equivalent to alternative A.a.2., but total emissions are considered, not just process emissions.

5.1.2. Group 2 – ETS

This group provides for an emission allowance market focusing on two emissions coverage possibilities: only industrial process emissions or total emissions. In the first case, although industrial energy emissions would not be considered in the ETS, they could be priced through a carbon tax. In the case of total emissions being priced, there would be no need for complementary pricing mechanisms to cover energy emissions as in the previous case.

In general, the alternatives of permits allocation differ in this group due to the additional burden of transferring revenue to the regulator through the purchase of certificates at the initial moment. There are two possibilities: (i) donation, in which the certificates are allocated free of charge among the agents; (ii) through some type of charge for the initial allocation of the certificates, usually through an auction system. Within these two cases, the issue of certificates can be done in an absolute (through the total amount of emissions) or relative way (through a benchmark). Therefore, two alternatives of allocation based on (i) and (ii) above will be proposed, considering that the marketing of certificates between agents in the ETS may generate revenues or expenses, depending on the initial amount.

5.1.2.1. Alternative B.a.1.

Considering only the industrial process emissions, this alternative takes into account a market of permits with free initial allocation of certificates. In an ideal distribution, the only cost to be incurred by the agents, in aggregate form, is the cost of abatement (either by the agent himself or by another one who sold him the certificate).

5.1.2.2. Alternative B.a.2.

This alternative is equivalent to the previous alternative (B.a.1.), so only the process emissions are considered, but in this case the certificates for industrial process emissions are sold to the agents through an auction system, and no longer distributed free of charge. Thus, in addition to the expenses incurred with abatement costs, agents also incur the cost of certificates for the amount of emissions they could not afford to pay ("double burden").

It should be noted that in this alternative there is revenue generation by the regulator, which can be reversed to support the industry or families, as well as the revenues from a possible carbon tax (group 1).

5.1.2.2. Alternative B.b.1.

This alternative is equivalent to the alternative B.a.1., but the energy emissions of the industry are incorporated, so the total emissions of the sector are covered. Similarly, this alternative offers a free initial allocation through an absolute or relative amount of certificates.

5.1.3.2. Alternative B.b.2.

This alternative is equivalent to alternative B.a.2, therefore it considers the total emissions, besides the initial allocation based on the auction of the permits, being able to be done in absolute or relative terms of certificates. Similarly, there is generation of revenue from the auctions, which can be reversed to support industry or families.

5.2. Analytical Comparison of Proposals

From the analyses carried out in the previous chapters and the presentation of possible institutional frameworks, it is possible to propose and compare the different arrangements of carbon pricing for the industrial sector. This comparison will be based on a SWOT Analysis (Table 25), whose main objective is to analyze the strengths and weaknesses, as well as the opportunities and the threats of each of the different climate policies.

According to CHIAVENATO and SAPIRO (2003), this analysis' function is to cross opportunities and threats (external/exogenous) with strengths and weaknesses (internal/endogenous). This evaluation, therefore, seeks to perform an environment analysis and serves to position or verify the situation of a company, a policy or a strategy. As SERRA, TORRES and TORRES (2004:28) conclude, "the primary function of SWOT Analysis is to enable an appropriate strategy to be chosen - to achieve certain objectives - from a critical assessment of internal and external environments."

In this way, carbon pricing proposals for the Brazilian industry can be analyzed and compared in terms of strengths and opportunities in relation to weaknesses and threats, favoring the possibilities of aligning each of these proposals with the reality of the sector. After carring out this analysis, the best proposal(s) of CPI(s) for each sector shall be chosen.

Table 25 – SWOT analysis of proposed CPI alternatives for industrial subsectors

Source: Own elaboration

Alternative	Strengths	Weaknesses	Opportunities	Threats
A.a.1.: Carbon Tax (Contribution) on process emissions with recycling for families	Stability of value for pricing Reducing the potential effect of loss of purchasing power by households	Does not consider energy emissions, then it needs to resort to another mechanism Resistance by industry Possibility of harming CPI discussions in the sector Does not solve the potential loss of competitiveness of the export-oriented industrial subsectors	Initial mechanism for wider taxation in the future Greater incentive to dynamic efficiency Possible positive effect for sectors of final consumer goods Opportunity to carry out distributive policy Favors discussions on Tax Reform	Possible effects on the trade balance Possible inflationary effects Possible effects on international competitiveness Possible carbon leakage Possible rebound effect
A.a.2.: Carbon Tax (Contribution) on process emissions with recycling to support industry	Stability of value for pricing Engagement of the industrial sector in the instrument formation process	Resistance by industry Possibility of harming CPI discussions in the sector Transfer of income from the consumer to the producer, generating possible adverse distributional effects Possible paradoxical effect, raising emissions	Recycling to gain productivity of the production factors Greater incentive to dynamic efficiency Favors discussions on Tax Reform	It may not solve the loss of household purchasing power May not generate increased productivity and create dependency Possible carbon leakage
A.b.1.: Carbon Tax (Contribution) on total emissions with recycling for families	Stability of value for pricing Reducing the potential effect of loss of purchasing power by households Broader scope - cost effectiveness	Greater resistance by industry Greater possibility of harming CPI discussions in the sector Does not solve the potential loss of competitiveness of the export-oriented industrial subsectors	Possible positive effect for sectors of final consumer goods Opportunity to carry out distributive policy Greater incentive to dynamic efficiency Favors discussions on Tax Reform	Greater possible effects on the trade balance Greater possible inflationary effects Greater possible effects on international competitiveness Greater possible carbon leakage Possible rebound effect
A.b.2.: Carbon Tax (Contribution) on total emissions with recycling to support industry	Stability of value for pricing o Broader scope - cost effectiveness Engagement of the industrial sector in the instrument formation process	Greater resistance by industry Greater possibility of harming CPI discussions in the sector Transfer of income from the consumer to the producer, generating possible adverse distributional effects Possible paradoxical effect, raising emissions	Recycling to gain productivity of the production factors Greater incentive to dynamic efficiency Favors discussions on Tax Reform	It may not solve the loss of household purchasing power May not generate increased productivity and create dependency Greater possible carbon leakage

B.a.1.: ETS on process emissions with free allocation	Ease of implementation/acceptance Aggregate emission range assurance	Does not consider energy emissions, then it needs to resort to another mechanism Uncertainty about carbon price Transaction Costs Political and legal challenges	Donating facilitates transition to CPI Initial mechanism, targeting other forms of wider allocation in the future Extensive international and national experience (CDM) Future opportunity for integration with other international markets Interaction with offsets	Windfall profits and/or implicit subsidies Collusive actions/market control with price impact
B.a.2.: ETS on process emissions with auction allocation	Generates revenue Knowledge of prices, does not distort incentives and reward previous actions Aggregate emission range assurance	Does not consider energy emissions, then it needs to resort to another mechanism Uncertainty about carbon price Transaction Costs Double burden - low acceptance	Recycling of revenue in the same way as recycling of carbon tax Incentive to dynamic efficiency Extensive international and national experience (CDM) Future opportunity for integration with other international markets Interaction with offsets	Collusive actions/market control with price impact Injury to smaller companies Very efficient MRV system need
B.b.1.: ETS on total emissions with free allocation	Ease of implementation/acceptance Aggregate emission range assurance Broader scope - cost effectiveness	Complexity in implementation and MRV Does not value previous actions Uncertainty about carbon price Transaction Costs	Donating facilitates transition to CPI Initial mechanism, targeting other forms of wider allocation in the future It shows interdependence and reinforces the need for intersectorial cooperation (offsets) Extensive international and national experience (CDM) Future opportunity for integration with other international markets	Windfall profits and/or implicit subsidies
B.b.2.: ETS on total emissions with auction allocation	Knowledge of prices, does not distort incentives and reward previous actions Generates revenue Aggregate emission range assurance Broader scope - cost effectiveness	Complexity in implementation and MRV Uncertainty about carbon price Transaction Costs Double burden - low acceptance Political and legal challenges	Recycling of revenue in the same way as recycling of carbon tax It shows interdependence and reinforces the need for intersectorial cooperation (offsets) Extensive international and national experience (CDM) Future opportunity for integration with other international markets	Injury to smaller companies Very efficient MRV system need

From the information in Table 25, it is possible to analyze the main strengths, weaknesses, opportunities and threats of the proposed alternatives. Given the specificity of the characterization of each alternative, it is observed that they have advantages and disadvantages, so that choosing one of them will be a direct function of their impacts, as well as political will and a possible sectorial lobby.

Regarding the choice of the CPI, it is believed that an ETS in the Brazilian industry would be more receptive to the sector, as well as suffer less political and legal challenges. This conclusion is based on a series of arguments, which will be presented below. Initially, and as discussed in chapter 3, given the complexity of the Brazilian tax system and the high tax burden, any attempt on taxation will face resistance from the population and companies (SANTOS et al., 2018; PEREIRA and BERTHOLINI, 2017). In this context, despite the process of Tax Reform, currently under discussion in the National Congress, it offers an opportunity to introduce tax instruments aimed at achieving the objectives of climate policy, it is not possible to see the effective realization of such reform in the short or medium term, especially due to the constant changes of political conjuncture and the uncertainties regarding the process of this reform in the Congress. Therefore, there is no political environment conducive to tax discussions. The PMR workshops about the Component 1, with the participation of the government, academia and companies of the industrial sector, also concluded that ETS would be more interesting than carbon taxes.

Despite the administrative simplicity of a tax, regulated entities generally prefer the emissions trading strategy. This preference is related to the desire to avoid an increase in the tax burden and to the possibility that fiscal revenues can be directed to investments that are not related to the climate transition (depending on the choice of the recycling way). In many cases, an ETS would provide regulated entities with greater flexibility and provide a fair basis for involvement in the climate change. This conclusion is also shared by the Brazilian Business Council for Sustainable Development (CEBDS) in a recent study on carbon pricing in the Brazilian industry, based on dialogues carried out directly with the sector (CEBDS, 2018).

Still, from the international experience (as discussed in chapter 2), especially focusing on the neighbors of Latin America, one can observe the region has gradually developed a number of initiatives on carbon pricing, mostly through the form of carbon taxes applied to fossil fuels. It should be noted, however, that the introduction of carbon taxes in countries such as Mexico, Argentina, Chile and Colombia, for example, was directly associated with and resulted from tax reforms in these countries (KONRAD ADENAUER STIFTUNG and GVCES, 2018). Despite this feature, transitions to an ETS from a carbon tax instrument, as already done by Mexico in 2018 and under consideration in the previous mentioned countries, suggest that carbon taxes have been used as transitional instruments for the development of ETS.

In this scenario, the implementation of an ETS in the Brazilian industry would allow for possible market linkages. Such possibility becomes even more relevant in the context of the Carbon Pricing in the Americas (CPA)[27], a cooperative framework launched in December 2017 by the government leaders of Canada, Chile, Colombia, Costa Rica, México, the Governors of California and Washington in the US, and the Premiers of Alberta, British Columbia, Nova Scotia, Ontario and Quebec in Canada. It vows to strengthen MRV schemes, develop common standards, share best practices, build capacities and engage stakeholders, whilst asserting CPIs' role as a central feature in climate policies. These market linkages conclusions were strongly highlighted in the Latin America Carbon Pricing Forum 2018 that took place in Sao Paulo in 2018, whose main outcomes are summarized in the policy brief "Carbon pricing instruments in Latin America" (KONRAD ADENAUER STIFTUNG and GVCES, 2018). CEBDS (2018) also reinforces such conclusions.

Looking beyond the Latin America region, Brazil's strategic trading partners, such as China and the European Union (EU) already have a functioning ETS, and by participating in this movement, the Brazilian industry could take advantage of the lessons learned from such experiences - which were analyzed in chapter 2 - in addition to possibly expand their presence in these economic markets. However, Brazil can also take advantage of its own experience in the context of the Clean Development Mechanisms (CDM), as the country was one of the main participants in the creation and regulation of this flexible instrument under Kyoto Protocol.

[27] Available at: <https://www.ieta.org/resources/News/Press_Releases/2017/Declaration%20on%20Carbon%20Pricing_FINAL.pdf> Accessed on: 07 November 2018.

Also, within the framework of the National Policy on Climate Change (NPCC) - as highlighted in chapter 3 -, the country established the Brazilian Emission Reduction Market (MBRE), which since 2009 aims to encourage the development of projects. Although CDM was a trade experience with Annex 1 countries under the Kyoto Protocol, MBRE transactions could enable the BM&FBOVESPA stock exchange to develop business instruments for the carbon market in an organized and transparent manner. Thus, the MBRE could provide input on how to develop an ETS in Brazilian industry.

Another more recent and relevant experience for a future national market is the Businesses for Climate Platform, an initiative of the Center for Sustainability Studies (GVces) of the School of Business Administration of the Getulio Vargas Foundation. This platform simulates a commercial emissions system, and it has 23 voluntary companies from various sectors of the Brazilian economy - not limited to the industrial sector (GVCES, 2017). This platform, which has been in operation since 2014, has its transactions made through the trading platform of the Rio's Green Stock Exchange (BVRio), based on the rules of the EU ETS and California Cap-and-Trade - both analyzed in this thesis. Its regulations and parameters are reviewed annually, from the actual data of companies' emissions, so that such experience can also offer insights on how to operate on an ETS.

Still, some of the large Brazilian companies monitor, report and verify their GHG emissions on a voluntary basis on platforms such as the Brazilian GHG Protocol Program and the Carbon Disclosure Project (CDP) Climate Change, and there are also reports on the mandatory state systems managed. This experience with MRV can also be valuable in efforts to standardize accounting and reporting regulations in the Brazilian carbon market.

Regarding emissions coverage, it should be emphasized that a CPI will be more cost effective as the number of emission sources/sectors participating increases, allowing the use of mitigation options with lower abatement costs, so a broader scope of emissions enables a greater number of abatement options. In this way, it is proposed the coverage of the total emissions and not only the process emissions. If only the process emissions are covered, there would be the need for the energy emissions to be priced by means of a carbon tax, for example, which could make the process even more complex. Thus, when considering the total emissions, there would be no need for complementary pricing mechanisms. Moreover, in the particular case of this thesis, considering total emissions becomes even more relevant in the context of which only the industrial subsectors with process emissions are considered (as highlighted in chapter 3), therefore other mitigation options (perhaps, with lower abatement costs) are no longer contemplated, due to the sectorial methodological cut[28]. Also, encompassing total emissions brings the opportunity to include other industrial sectors' emissions, therefore increasing the competitiveness across the ETS and enabling gains in the system's cost effectiveness.

When considering an ETS, the scope also influences the atomization of the market. In order for the equilibrium price of a market to be efficient and adequately represent the marginal cost of abatement (that is, in order for the price of the permit to be equal to the marginal cost of the last abatement unit), it is necessary to have a competing market. When considering only the process emissions, a great concentration of emissions is observed in few agents, who could have market power to influence prices and to move away from the condition of allocative efficiency.

Finally, regarding the characterization of the instrument (free allocation or auction), it can be concluded from chapter 4 that at least a medium carbon leakage exposure would become an expected but not a desired outcome of the CPI on the Brazilian industrial sector. From the international experience analyzed in chapter 2, the allocation method is crucial when designing an ETS, especially for the carbon leakage risk sectors. For this reason, free allocation is proposed for the subsectors analyzed, at least during the beginning of the ETS operation[29]. Such propose is also in line with the discussions held in the PMR workshops, as well as with the study developed by CEBDS (2018). As a best practice also discussed in chapter 2, especially from the EU ETS lessons, the proposed ETS should be phased in over five-year periods so that adjustments and corrections of possible market imperfections may occur.

[28] It is noteworthy that such sectorial follows the characterization used by the Ministry of Finance (MF), within the scope of the PMR project, and the Ministry of Industry, Foreign Trade and Services (MDIC) in the context of the Industry Plan (MDIC, 2013).
[29] An ETS with auction would be equal to a carbon tax, since, in addition to the costs incurred with abatement costs, the agents also incurred in the cost of certificates for the amount of emissions they could not afford (double burden).

As the free allocation system was chosen as a proposal, it is necessary to determine the distribution criteria of these allowances. Historical emissions, production level or other pre-set standard can be used to define this distribution pattern (IEA, 2000). Traditionally, it has been the form adopted by the markets that begin their operations, as the international experience pointed out (discussed in chapter 2). This form of distribution reduces the costs of the program to the regulated sectors, since they receive an asset free of charge, besides eliminating the costs added to the firms, without any implication in the efficiency of the program and with clear political advantages (BAUMOL and OATES, 1988).

The grandfathering (GF) option, in which past emissions are generally used to define future needs for certificates, is proposed as the free allocation method. It requires consistent emission data and a special attention should be given to the issue of reservations to incoming companies – they will need new allocation criteria – and how to deal with those who have closed their activities. Furthermore, such a system is a more politically feasible possibility for starting a CPI, while maintaining the possibility of gradually migrating towards auction systems. As a conclusion, *the CPI design proposed is the alternative B.b.1, that is, an ETS covering total industrial emissions based on a free allocation method.*

6. Conclusions

This chapter summarizes this thesis and presents its main conclusions, besides evaluating the main limitations and possible future studies that can be carried out from these results (and limitations) found in this thesis.

6.1. Main Conclusions

After the COP 21 and the subsequent adoption of the Paris Agreement in December 2015, the outlook for carbon pricing policies has been widened. While the Agreement does not directly make room for a global carbon price, the provisions set out in Article 6 have the potential to increase international cooperation in favor of mitigation through market mechanisms (CEBDS, 2016).

During the conference, Brazil announced a target to reduce its GHG emissions by 37% if compared to 2005 levels by 2025 and the intention to reduce 43% of such emissions by 2030. Several mitigation strategies were envisioned and quantitatively described in the Brazilian NDC to be achieved by 2030, such as reforestation and increase in the share of bioenergy in the Brazilian energy system (GURGEL and PALTSEV, 2017; MCTI, 2016a). However, considering the industrial sector, there are neither details nor precise quantifications. Brazil's NDC only mentions that "the industrial sector should promote mitigation actions based on new clean technologies standards, energy efficiency measures and low carbon infrastructure" (BRAZIL, 2015a, b).

Thus, one can characterize as a vague and comprehensive the previsions of the Brazilian NDC regarding the industrial sector, which makes it difficult to measure the low emission efforts to be directed to the industrial sector, as well as potential results of the measures adopted. On the other hand, NDC's generality makes it possible to consider the various mitigation opportunities, especially taking into account the fact that the Brazilian NDC also considers the possible use of market mechanisms, although there is no indication as to how these instruments would be used. According to the text, the country reserves its position on the possibility of using the mechanisms that may be established under the Paris Agreement (BRAZIL, 2015b).

Although NDC does not describe how or whether carbon will be priced in Brazil, studies to evaluate possible CPI impacts in the country have been considered by the Federal Government at least since 2011 (MF, 2014). In addition, there are a number of studies that quantitatively analyze the economic impacts on the Brazilian industry given the implementation of CPIs, considering ETS, carbon tax or hybrid systems. Still, there is a gap with regard to more focused studies capable of analyzing these impacts considering different policy and instrument designs. At the same time, few national studies analyze the economic impacts of CPIs in both domestic and international perspectives, taking into account competitiveness indicators, international trade, and commercial balance. Additionally, such studies fail to investigate existing indirect impacts on other economic sectors, once intersectorial connections are also present. Theses aspects also configure a relevant void in the literature and this thesis aimed to fill it.

In this context, the primary benefit of a well-designed competitiveness policy is that it would mitigate and potentially eliminate risks to competitiveness. It is widely recognized that the problem of carbon leakage poses a major challenge for designing effective unilateral policies aimed at mitigating global climate change, reason why this topic represents one of the major analysis of this thesis, whose general goal is to propose an institutional framework for CPI in the Brazilian industry directed to reduce its domestic vulnerability and international trade exposure.

For that, the international experience was reviewed in chapter 2. When looking at the ETS experiences, four cases were analyzed: EU ETS, California Cap-and-Trade, NZ ETS, and China ETS. They were compared in terms of emissions cap, allowance allocation and distributional method, price control mechanisms, carbon leakage assessment, international linking possibilities, and carbon revenue management. Regarding carbon taxes experiences, the following practices were inspected: Norway's Carbon Tax, British Columbia Carbon Tax, Australian CPM, and Mexico Carbon Tax. They were compared in terms of pricing settings, sectorial coverage, carbon leakage assessment, and carbon revenue management.

Some lessons can be learnt from these international experiences. An ETS, rolled out with dynamically adjustable emission caps based on stakeholder feedback and new emissions data (e.g., Chinese pilots), has been shown to result in price stability and cost-effective emissions reductions. An ambitious coverage and free allowances seem to be initially more politically palatable, but transitioning to auctioning of allowances over time (e.g., California and EU ETS phase 3) ensures simultaneous revenue generation. Besides, a price floor/ceiling (or "collar") creates a more stable market with less price volatility (e.g., California Cap-and-Trade) and may lower compliance costs in the long run. International linkage benefits smaller markets by reducing abatement costs, increasing liquidity, and achieving cost effectiveness, and soft linkages to offset markets without a cap on such offsets can result in excess supply and price collapse (e.g., NZ ETS). Finally, managing the level of price caps, the percentage of banking and borrowing between phases, the amount of reserve allowances, and the ability to adjust these levers quickly in the market could ensure a predictable marketplace with stable prices and sufficient liquidity.

Relatively to carbon taxes lessons, four cases were analyzed: Norway's Carbon Tax. British Columbia's Carbon Tax, Australia CPM, and Mexico Carbon Tax. Conclusion highlight that low tax rates per ton of CO_2 (e.g., Mexico) with no mechanisms to increase the future tax rate may reduce and eventually nullify the price effect of the tax on emission reductions over time. In addition, a clear, stable, and steady tax rate increase is necessary to drive deeper emission reductions, as well as to send transparent market signals to private actors that climate policy is a long-term and economy-wide policy. Exempting emission-intensive trade competitive sectors (e.g., shipping in Norway and natural gas in Mexico, and industry in the four experiences) from carbon taxation undermines the purpose of a carbon tax. Still, for systems that impose both a carbon tax and ETS across sectors (for instance, Norway and Mexico), it is important to identify whether there is an overlap of carbon tax and ETS on the same emissions base (e.g., the electricity and industrial sectors in Norway) and ensure that the overlap does not have distributional consequences or lead to increased, economically-inefficient abatement costs. From the international experience, some CPI begins as a carbon tax and then they become (or starts to interact) with an ETS (e.g., Mexico).

It should be noted that the introduction of a CPI could have a number of effects and impacts on economic sectors, especially on the more carbon intensive ones. Certainly, such impacts can influence the competitiveness of a sector, being directly associated with some possible risks, among which economic, environmental and political risks, which will be analyzed below. Therefore, when addressing this challenge, there are two key (and interrelated) questions that policy makers need to consider: (i) which sectors should be targeted (supported) by the leakage prevention mechanism? and (ii) what form should that leakage prevention mechanism take? This thesis analyzed some mitigation policies, among them free allowance allocations, border taxes adjustments, administrative exemptions, tax free thresholds, and output based rebates. The main conclusion is that policy makers must weigh the specific advantages and disadvantages of each leakage prevention measure in the context of their particular circumstances, i.e., there is no general rule to be applied in all situations.

The Brazilian industry, the target sector of this thesis, was deeply analyzed in terms of economic characterization and sectorial emissions profile. Information regarding seven Brazilian industrial subsectors (Aluminum, Cement, Lime and Glass, Chemicals, Pig Iron and Steel, and Pulp and Paper) was collected. As defined in chapter 3, the decision to divide the industry in these seven subsectors follows the characterization used by the Ministry of Finance (MF), within the scope of the PMR project, and the Industry Plan. Such subsectors are those that have emissions process, and, according to the analysis carried out in chapter 2, these are the main industrial sectors considered in the context of designing carbon pricing policies and their instruments.

From an economic perspective, based on the indicators calculated from the 2010 Input-Output Matrix (IBGE, 2015), individual analyses of sectorial characteristics were carried out and subsequently a comparative analysis was executed, especially in terms of sector importance, through its Gross Value of Production (GVP) and its Value Added (VA), in relation to the values of the manufacturing industry and the sectors analyzed. Then, the external vulnerability of these subsectors is evaluated by the Export Coefficient (EC).

With regard to the emissions profile, subsectorial details were presented, based on the Third National Communication of Brazil to the UNFCCC (MCTI, 2015), and also a comparative analysis was performed. The compilation of the results indicates a total of 121,493 $GgCO_2$ equivalent in 2010, being 61.4% of this value associated with industrial process emissions, while the rest (38.6%) relates to the consumption of energy. Pig Iron and Steel sectors are the most significant, accounting for 37% of emissions, also leading on process emissions with a total of 53%, followed by the Cement and Chemical sectors, with about 30% and 14% respectively, that also presented the two largest volumes of energy emissions, with around 30%.

The mapping of existing sectorial policies was also carried out in chapter 3, organized into five policy groups, as in the methodology carried out in the Brazilian PMR Project – Component 1 (industrial sector): (i) sectorial stimulus policies, (ii) rational use of resources policies, (iii) tax policies, (iv) climate policies and (v) environmental policies with emphasis on atmospheric emission control. Its qualitative analysis was developed in chapter 4, by identifying effect (i) on the agents' competitiveness; (ii) social impacts focusing on the consumers' purchasing power; and (iii) the national level of emissions of GHG. Another qualitative analysis related to the effects of different CPI designs (ETS: allocation methods; carbon tax: recycling ways) was carried out, looking at the same three impacts. The results from these qualitative assessments were used to support the CPI proposal in the chapter 5.

Also, a quantitative evaluation helped to define this proposal. It was based on the methodologies used to analyze carbon leakage risk in three jurisdictions: EU ETS, California Cap-and-Trade and Australian CPM. After describing, evaluating and comparing their indicators, they were applied to the Brazilian industrial sector, in order to assess the risk of carbon leakage in the subsector level. The main conclusion obtained is that all subsectors would face some level of carbon risk (medium to high), except the Pulp and Paper in the specific case of using the EU ETS methodology. In all other scenarios considered, at least a medium carbon leakage exposure would become an expected but a not-desired outcome of a CPI on the Brazilian industrial sector, as concluded by SANTOS et al., (2018). An average result would arise from using the Australian CPM methodology, when all subsectors would be classified as medium risk. If the California Cap-and-Trade methodology is applied, all sectors are classified at least as medium-risk, being Aluminum and Pig Iron and Steel labeled as highly exposed.

Lessons learned from the international experiences, besides the qualitative and quantitative analysis, supported the definition of the institutional frameworks for CPI in the Brazilian industry. Three main points were studied: (i) analysis of the institutional arrangements for a CPI; (ii) evaluation and comparison of possible carbon pricing arrangements in the sectors under a SWOT Analysis; and (iii) possible interactions between the industrial sector and other sectors, such as fuels, the electricity sector and LULUCF.

The results show that different instrument arrangements are better or worse depending on the impact to be minimized. Arrangements were evaluated with an emphasis on reducing effects on competitiveness and purchasing power. They are combinations of the following elements: type of price instrument (carbon tax or ETS); scope of emissions (total or only process emissions); and characterization of the instrument (in the case of a carbon tax, the recycling ways and, in the case of an ETS, the forms of allocation).

Regarding the taxation options (group 1), in addition to assessing the coverage of the emissions necessary to guarantee the CPI, it was highlighted that the form of carbon recycling leads to quite different effects. If on the one hand the transference to families has distributive potential, it also takes a toll on the competitiveness of the industry. Conversely, recycling through industry support can reduce negative effects on competitiveness, however this approach may have perverse distributive effects (regressive taxation).

It was concluded that carbon tax tends to face resistance from the industry, especially coming from those subsectors exposed to foreign trade, that is, that present a high risk of carbon leakage, reason why the biggest contribution of this thesis in terms of policy is that proposals related to the implementation of an ETS seem more interesting.

In this context, considering the ETS-based arrangements (group 2), and with respect to the scope of emissions, it was concluded that an important element is the attempt to increase the atomization and competition of the carbon market, avoiding that agents with relatively large emissions volumes gain power and affect price formation. In this sense, considering the total emissions (energy and process) as well as possible interactions with other sectors via offset can be an interesting alternative. Thus, when considering the total emissions, the number of agents and the volume of permits traded increase. Furthermore, it eliminates the need for additional instruments to reduce energy emissions in the industry.

The forms of allocation considered are basically distinguished from the initial cost of the allowances, which may include an additional cost or not. The auction has the advantage of enabling the regulator to discover agent reserve prices, not distort incentives and reward prior actions. Also, there is the possibility of recycling the revenue just as it occurs in the carbon tax case. However, as evidenced by international experience, the auction will be refrained by the industry and possibly lead to carbon leakage.

The donation of certificates is considered as the possibility with less resistance by the industry, since it reduces the burden of the instrument, at least during the beginning of the ETS operation. As the international experience shows, it is interesting to define a phased ETS in over five-year periods so that adjustments and corrections of possible market imperfections may occur.

However, such free allocation must be made in such a way as to avoid extraordinary profits, and/or implicit subsidies. Thus, the definition of the quota distributed to each agent must be done in a careful way so that the mitigation effort is maintained. In this sense, relatively to the distribution criteria, a grandfathering (GF) option is proposed. It is focused on past emissions and traditionally it has been the form adopted by markets at the commencement of their operations, as pointed out by the international cases, since it reduces the costs of the program to the regulated sectors.

Finally, also as shown by the international practices, there is a possibility of a transition in the allocation form (from donation to auction), as the subsectors adjust to the CPI. This possibility can be an alternative that gradually increases the cost for companies, giving them time to adapt, and it allows the generation of revenues in the long term, which can be reverted to distributive or supportive mechanisms for the industry.

6.2. Main Limitations

Two main limitations of this thesis can be highlighted. The first is focused on the coverage of the industrial subsectors analyzed, while the second is related to the interactions of industry with other sectors.

As described in chapter 2, information regarding seven Brazilian industrial subsectors (Aluminum, Cement, Lime and Glass, Chemicals, Pig Iron and Steel, and Pulp and Paper) was collected in this thesis. The decision to divide the industry in these seven subsectors follows the characterization used by the Ministry of Finance (MF), within the scope of the PMR project, and the Industry Plan. Such subsectors are those that have emissions process. Also, according to the analysis carried out in the section 2.2, these are the main industrial sectors considered in the context of designing carbon pricing policies and their instruments.

Regarding emissions coverage, regardless the CPI adoption, it should be emphasized that the instrument will be more cost effective as the number of emission sources/sectors participation increases, allowing the use of mitigation options with lower abatement costs. Thus, a broader scope of emissions enables a greater number of abatement options, as discussed in chapter 5. In this way, perhaps it would be interesting to analyze all industrial subsectors (including those that only have energy emissions). This scope influences the atomization of the market, so having more subsectors covered could avoid market power to influence prices and to move away from the condition of allocative efficiency.

Furthermore, it is understood that the definition of an arrangement for a CPI in the Brazilian industry will need to take into account the interaction with other sectors. Thus, it is possible that the institutional arrangement of a CPI is formulated, in an intersectorial way, including the sectors of fuels, electricity generation and AFOLU. As said above, that cost-effectiveness of a national mitigation policy depends on the number of participating sectors. The more comprehensive the pricing instrument, the greater the use of mitigation options with lower abatement costs. However, the interaction between sectors may not be trivial considering specific characteristics of Brazil in terms of its emissions profile and the peculiarities found in its energy sector (electricity and fuels) – it is valid to note this topic was not in the scope of this thesis. Either way, these interactions should be properly and carefully assessed.

6.3. Recommendations for Future Studies

After describing two limitations of this thesis, a list of recommendation for future studies follows, but other possibilities are also highlighted:

- Analyze the CPI implementation in the Brazilian industry considering not only sectors that have process emissions, but also those that do not have this type of emissions, i.e., sectors with only energy emissions;
- A deep analysis regarding CPI interactions among industry and other sectors like fuel, electricity and AFOLU, perhaps though the use of CGE models;
- Also evaluate the chosen institutional design and framework, besides the role of major players involved in the industrial CPI implementation;
- Study the possibilities and alternatives to MRV designs in order to support the management of the CPI;
- Analyze the ETS linking possibilities in the context of Carbon Pricing in the Americas (CPA), which was launched in December 2017, placing special focus on Latin America;
- Analyze climate policy in the context of legal proceedings and the actions of insurance companies regarding economic damages and the definition of property rights;
- Provide a greater and better disaggregated sectorial database, especially in sectors with high heterogeneity, such as the Chemical sector;
- Assess the feasibility of discussing and proposing a (Green) Tax Reform in the context of CPI implementation in Brazil.

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Annex A – Methodology for Economic Characterization

This annex presents a further breakdown of section 3.2, specifying the methodology of the indicators used in the characterization of the industrial sector and its subsectors.

The input-output system integrated to the National Accounts gives rise to the Production Matrices, which informs what each sector of the economy produces of each product, and the Uses and Resources Matrices, which supplies the quantity of inputs that each sector uses to carry out its production. The combination of these two pieces of information results in the input-output matrix, which decomposes monetary flows between economic activities and primary factors, describing the internal structure of each productive sector and the economy as a whole. This structure is often used to analyze impacts on the sectors of a particular economy. Impacts can be calculated through economic indicators and multipliers, which allow, for example, the verification of the effects of a change in the final demand of a given sector on total production, income or employment (MILLER and BLAIR, 1984). The indicators used in the sectorial characterization are described in the following sections.

A.1. General Characterization

The aluminum sector, according to the new, very detailed series of the System of National Accounts and the Input-Output Matrix 2010 (IBGE, 2015), falls within activities *0792 - Extraction of nonferrous metallic minerals, including processing*, whose product corresponds to *07921 - Non-ferrous metal ores*, and *2492 - Non-ferrous metal metallurgy and metal casting*, whose products correspond to *24921 - Non-ferrous metal metallurgy products* and *24922 - Castings, steel and non-ferrous metals*.

Regarding the data retrieved from the Annual Social Information Ratio (RAIS), available at the Central Business Register (IBGE, 2014), the aluminum sector is classified into activity *0700 - Extraction of metallic minerals*, whose product corresponds to *07.2 - Extraction of non-ferrous metals*, and *2400 - Metallurgy*, whose product corresponds to *24.4 - Metallurgy of nonferrous metals*. In this sense, this thesis assumes that the classification of non-ferrous metals would be equivalent to the aluminum sector, in the absence of more detailed primary information.

The Cement, Lime and Glass sectors, according to the new, very detailed series of the System of National Accounts and the Input-Output Matrix 2010 (IBGE, 2015), are framed within activities *0580 - Extraction of coal and non-metallic minerals* and *2300 - Manufacture of non-metallic mineral products*, whose products correspond to *23001 - Cement* and *23003 - Glass, ceramics and other products of non-metallic minerals* (there is no specific product to characterize the lime subsector).

Concerning the data retrieved from the Annual Social Information Ratio (RAIS), available at the Central Business Register (IBGE, 2014), the Cement, Lime and Glass sectors are classified within activity *2300 - Manufacture of nonmetallic mineral products*, whose products correspond to *23.2 - Manufacture of cement* and *23.1 - Manufacture of glass and glass products* (also there is no specific product to characterize the lime subsector). For certain indicators, it was necessary to group these activities forming the sector called Cement, Lime and Glass.

The chemical sector, according to new, very detailed series of the System of National Accounts and the Input-Output Matrix 2010 (IBGE, 2015), is falls within the following activities: *2091 - Manufacture of organic and inorganic chemicals, resins and elastomers*, whose products correspond to *20911 - Inorganic chemicals*, *20912 - Fertilizers and soil conditioners*, *20913 - Organic chemicals* and *20914 - Resins, elastomers and artificial and synthetic fibers*, *2092 - Manufacture of pesticides, disinfectants, paints and various chemicals*, whose products correspond to *20921 – Agricultural pesticides and household cleaning disinfectants*, *20922 - Miscellaneous chemical products*, *20923 - Paints, varnishes, enamels and lacquers*, *2093 - Manufacture of cleaning products, cosmetics/perfumery, and personal hygiene products*, whose product corresponds to *20931 - Perfumery, soaps and cleaning products* and *2100 - Manufacture of pharmaceutical and pharmaceutical chemical products*, whose product corresponds to *21001 - Pharmaceutical products*.

Regarding the data retrieved from the Annual Social Information Ratio (RAIS), available at the Central Business Register (IBGE, 2014), the Chemical sector is classified into the following activities: *2000 - Manufacture of chemical products*, whose products correspond to *20.1 - Manufacture of inorganic chemicals*, *20.2 - Manufacture of organic chemicals*, *20.3 - Manufacture of resins and elastomers*, *20.4 Manufacture of artificial* *and synthetic fibers, 20.5 Manufacture of pesticides and disinfectants, 20.6 - Manufacture of soap, detergents, cleaning products, cosmetics, perfumery and personal hygiene products, 20.7 - Manufacture of paints, varnishes, enamels, lacquers and related products, 20.9 Manufacture of various chemical products and preparations,* and *2100 - Manufacture of pharmaceutical and pharmaceutical chemical products*, whose product corresponds to *21.1 Manufacture of pharmaceutical chemical products* and *21.2 Manufacture of pharmaceutical products*.

The Pig Iron and Steel sector, according to the new, very detailed series of the System of National Accounts and the Input-Output Matrix 2010 (IBGE, 2015), falls within activities *0791 - Extraction of iron ore, including processing and agglomeration*, whose product corresponds to *07911 - Iron ore*, and *2491 - Production of pig iron/ferroalloys, steel and seamless steel tubes*, whose products correspond to *24911 - Pig iron and ferroalloys* and *24912 - Semi-finished products, rolled, flat and steel tubes*.

Regarding the data retrieved from the Annual Social Information Ratio (RAIS), available at the Central Business Register (IBGE, 2014), the Pig Iron and Steel sector falls within activities *0700 - Extraction of metallic minerals*, whose product corresponds to *07.1 - Extraction of iron ore*, and *2400 - Metallurgy*, whose products correspond to *24.1 - Manufacture of pig iron and ferroalloys, 24.2 - Steel, 24.3 - Manufacture of steel tubes, other than seamless tubes, 24.5 - Casting*.

The Pulp and Paper sector, according to the new, very detailed series of the System of National Accounts and the Input-Output Matrix 2010 (IBGE, 2015), falls within the activities of *1700 - Manufacture of pulp, paper and paper products*, whose products correspond to *17001 - Pulp* and *17002 - Paper, paperboard, packaging and paper articles*.

Regarding the data retrieved from the Annual Social Information Ratio (RAIS), available at the Central Business Register (IBGE, 2014), the Pulp and Paper sector is classified into activity *1700 - Manufacture of pulp, paper and paper products,* whose products correspond to *17.1 - Manufacture of paper and paperboard, 17.2 - Manufacture of pulp and other paper pulp, 17.3 - Manufacture of paper products, paperboard, paper card and corrugated cardboard,* and *17.4 - Manufacture of various paper products, paperboard, paper card and corrugated cardboard.*

A.2. Sectorial Structure of the Gross Value of Production

The distribution structure of the gross production value (GPV) of the sector indicates the most relevant sectors in terms of production value, allowing for a specific analysis on the importance (in terms of production value) of the target sectors, as carried out in this thesis, in relation to the total production of the economy. The indicators used in this study were calculated by the participation of the GPV of the subsectors in the sectorial GPV, GPV of the transformation industry, as well as in the GPV of the total economy. The data source is Table 1 – Production, belonging to the Resource Matrix (IBGE).

$$\%GPV_i = \frac{GPV_i}{GPV}$$

In which $\%GPV_i$ is the indicator of the sectorial structure of the production value; GPV_i is the gross production value of subsector i; and GPV is the gross production value of selected sectors of this thesis/transformation industry/total economy.

A.3. Sectorial Structure of the Value Added

The distribution structure of the sectorial value added (VA) indicates the most relevant sectors in terms of value added, allowing for a specific analysis on the importance (in terms of value added) of the target sectors, as carried out in this thesis, in relation to the total production of the economy. The indicators used in this study were calculated by the participation of the VA of the subsectors in the sectorial VA, transformation industry VA, as well as in the total GDP of the economy. The data source is Table 1 – Production, belonging to the Resource Matrix (IBGE).

$$\%VA_i = \frac{VA_i}{VA}$$

In which $\%VA_i$ is the indicator of the sector structure of the value added; VA_i is the value added of the subsector i; and VA is the value added of selected subsectors of this thesis/transformation industry/total economy.

A.4. External Vunerability – Export Coefficient

It is also interesting to identify, in order to verify the impact on sector competitiveness, both the participation of exports in production and the vulnerability to foreign trade of the different industrial subsectors of this thesis. These issues are analyzed on the basis of the export coefficient. Carbon pricing imposes additional risk of vulnerability due to loss of domestic market in import parity or loss of market for exporter in export parity. A domestically highly concentrated sector may be challenged by its external vulnerability (e.g., the national petrochemical sector). A sector with low external vulnerability, if concentrated, is more likely to impose higher prices without loss of market, in case its product is not elastic (price elasticity of demand). That is, the company can impose a price mark-up, transferring the carbon cost to the consumer.

The export coefficient (EC) is the percentage of production that is exported, so that the higher the EC, the greater the importance of external sales to the industry. It is calculated by the ratio between the exports by subsector and the GVP of the subsector. The source of information is Table 1 – Production, belonging to the Resources Matrix (IBGE) and Table 2 – Exports, belonging to the Uses of Goods and Services Matrix (IBGE).

$$EC_i = \frac{E_i}{GVP_i}$$

In which EC_i is the export coefficient; E_i are the exports of the subsector i; and GVP_i is the gross value of production of the subsector i.

Annex B – Methodology for Sectorial Emissions Profile

This annex presents a further breakdown of section 3.3., specifying GHG emissions by industry subsector. Information regarding the emissions of the seven Brazilian industrial subsectors analyzed, namely Aluminum, Cement, Lime and Glass, Chemicals, Pig Iron and Steel, and Pulp and Paper, were collected[30]. The emissions were disaggregated in "Process Emissions" and "Energy Emissions" according to the classification of the Third Brazilian Inventory of Anthropogenic Greenhouse Gas Emissions and Removals (MCTI, 2015).

B.1. Aluminum

The aluminum sector in 2010 reached a total of 2,544 Gg CO_2, caused by the industrial process. Table 26 shows the industry's process emissions history, which highlights the prevalence of emissions from the Prebaked Anode process.

In Brazil the type of technology used varies from plant to plant. In 2010, around 56% of the national primary aluminum production used the Prebake method, while the other 44% used the Soderberg method (ABAL, 2011).

[30] As mentioned in chapter 3, I would like to thanks the following fellows from CENERGIA/COPPE/UFRJ for supporting me in this sectorial analysis: Raphael Guimarães, Fernanda Guedes, Paula Guedes, and Bruno Cunha.

Table 26 – CO_2 emissions from process of the Brazilian aluminum sector (Gg CO_2)

Source: MCTI (2015)

CO_2 Emissions (Gg CO_2)			
Year	**Soderberg Process**	**Prebaked Anode Process**	**Total**
1990	672	902	1,574
1991	726	1,175	1,901
1992	756	1,256	2,012
1993	698	1,248	1,946
1994	692	1,264	1,956
1995	707	1,258	1,965
1996	722	1,259	1,981
1997	720	1,255	1,975
1998	741	1,266	2,007
1999	773	1,306	2,079
2000	791	1,325	2,116
2001	701	1,178	1,879
2002	771	1,405	2,176
2003	818	1,380	2,198
2004	957	1,451	2,408
2005	1,002	1,471	2,473
2006	1,072	1,574	2,646
2007	1,154	1,585	2,739
2008	1,173	1,580	2,753
2009	1,122	1,423	2,545
2010	1,143	1,401	2,544

The process emissions of other GHGs in the production of Brazilian aluminum are presented in the Table 27.

Table 27 – Emissions of others GHGs from process of the Brazilian aluminum sector (ton)

Source: MCTI (2015)

CF_4 Emissions (ton)				C_2F_6 Emissions (ton)		
Year	**Soderberg**	**Prebaked Anode**	**Total CF4**	**Soderberg**	**Prebaked Anode**	**Total C2F6**
1990	140.7	161.5	302.2	9.2	17.1	26.3
1991	153.3	183.3	336.6	10.1	19.0	29.1
1992	150.6	205.9	356.5	9.8	21.3	31.1
1993	138.2	196.7	334.9	8.8	20.2	29.0
1994	131.6	191.6	323.2	8.4	19.5	27.9
1995	125.3	180.7	306.0	8.1	18.2	26.3
1996	114.3	183.3	297.6	7.5	18.6	26.1
1997	89.5	113.3	202.8	5.7	10.0	15.7
1998	93.2	134.5	227.7	5.9	11.3	17.2
1999	102.1	99.2	201.3	6.6	8.7	15.3
2000	74.3	72.2	146.5	5.1	6.6	11.7
2001	52.1	62.6	114.7	3.4	5.8	9.2
2002	52.4	82.7	135.1	3.3	8.4	11.7
2003	61.1	75.1	136.2	4.0	7.5	11.5
2004	58.3	65.8	124.1	3.9	6.1	10.0
2005	63.6	60.3	123.9	4.2	6.1	10.3
2006	61.3	60.5	121.8	4.2	6.2	10.4
2007	62.5	54.9	117.4	4.3	5.6	9.9
2008	62.7	51.8	114.5	4.3	5.3	9.6
2009	61.1	21.2	82.3	4.2	2.2	6.4
2010	59.7	17.0	76.7	4.1	1.8	5.9

From the Global Warming Potential (GWP) values of GHGs emitted in the aluminum production, it is possible to calculate the emissions in CO_2 equivalent as shown in Table 28.

Table 28 – Process emissions of the Brazilian aluminum sector (Gg CO_2eq)

Source: Own elaboration based on MCTI (2015) and IPCC (2006).

Year	CO_2 Emissions ($Gg\ CO_2$)	CF_4 Emissions ($Gg\ CH_4$)	C_2F_6 Emissions ($Gg\ C_2F_6$)	Total Emissions ($Gg\ CO_2eq$)
1990	1,574	2,004	2,922	6,500
1991	1,901	2,232	3,233	7,366
1992	2,012	2,364	3,455	7,831
1993	1,946	2,220	3,222	7,388
1994	1,956	2,143	3,100	7,199
1995	1,965	2,029	2,922	6,916
1996	1,981	1,973	2,900	6,854
1997	1,975	1,345	1,744	5,064
1998	2,007	1,510	1,911	5,428
1999	2,079	1,335	1,700	5,113
2000	2,116	971	1,300	4,387
2001	1,879	760	1,022	3,662
2002	2,176	896	1,300	4,372
2003	2,198	903	1,278	4,379
2004	2,408	823	1,111	4,342
2005	2,473	821	1,144	4,439
2006	2,646	808	1,155	4,609
2007	2,739	778	1,100	4,617
2008	2,753	759	1,067	4,579
2009	2,545	546	711	3,802
2010	2,544	509	655	3,708

Energy emissions were calculated from the energy consumption of the sector, as shown in the Table 29. Using the emission factors of electricity (14.2 GJ/t CO_2) and fuel oil (77.1 GJ/t CO_2), and then converting them to Gg of CO_2, the results presented in Table 30 are obtained.

Table 29 – Energy consumption in the aluminum sector (GJ and %)

Source: MCTI (2015)

Year	Electricity		Fuel Oil		Total
	GJ	%	GJ	%	GJ
2005	87,300	73.0	32,248	27.0	119,548
2006	92,394	75.1	30,674	24.9	123,068
2007	95,276	75.1	31,601	24.9	126,878
2008	97,983	76.6	29,858	23.4	127,842
2009	90,648	76.6	27,750	23.4	118,397
2010	93,093	75.1	30,870	24.9	123,963

Table 30 – Energy consumption in the aluminum sector (Gg CO_2 and %)

Source: MCTI (2015)

Year	Electricity		Fuel Oil		Total
	Gg CO_2	%	Gg CO_2	%	Gg CO_2
2005	1,240	33.,3	2,486	66.7	3,726
2006	1,312	35.7	2,365	64.3	3,677
2007	1,353	35.7	2,436	64.3	3,789
2008	1,391	37.7	2,302	62.3	3,693
2009	1,287	37.6	2,139	62.4	3,427
2010	1,322	35.7	2,380	64.3	3,702

Thus, for 2010, a total of 7,410 Gg CO_2 is obtained, in which 3,702 Gg CO_2 are from the emission of energy and 3,708 Gg CO_2 from the industrial processes.

B.2. Cement, Lime and Glass

The history of GHG process emissions from process in the cement industry is shown in Table 31, indicating a total of 21,288 Gg CO_2 in 2010. The energy emissions are presented in the Table 32. The total emissions of the sector in the year 2010 were 35,907 GgCO_2.

Table 31 – Process emissions from the cement sector (Gg CO_2)

Source: MCTI (2015)

Year	CO_2 Emissions (Gg CO_2)	Process Emission Factor(t CO_2/t product)	
		Clinker	CO_2 Emissions
1991	11,776	0.549	0.428
1992	9,770	0.550	0.409
1993	10,164	0.552	0.409
1994	10,086	0.548	0.400
1995	11,528	0.547	0.408
1996	13,884	0.548	0.401
1997	15,267	0.546	0.401
1998	16,175	0.545	0.405
1999	16,439	0.549	0.409
2000	16,047	0.549	0.402
2001	15,227	0.548	0.386
2002	14,390	0.550	0.370
2003	13,096	0.553	0.373
2004	13,273	0.554	0.369
2005	14,349	0.545	0.371
2006	15,440	0.542	0.369
2007	17,200	0.541	0.369
2008	18,884	0.548	0.363
2009	19,031	0.548	0.368
2010	21,288	0.544	0.360

Table 32 – Energy emissions in the cement sector (Gg gas)

Source: MCTI (2015)

Year	CO_2 Emissions ($Gg\ CO_2$)	CH_4 Emissions ($Gg\ CH_4$)	N_2O Emissions ($Gg\ N_2O$)	CO Emissions (Gg CO)	NO_X Emissions ($Gg\ NO_X$)	NMVOC Emissions (Gg NMVOC)
1991	6,585	2.3	0.12	49.3	18.1	2.2
1992	5,149	1.9	0.09	38.7	13.2	1.6
1993	5,131	2.1	0.09	41.5	12.9	1.6
1994	5,060	2.3	0.10	46.9	13.0	1.7
1995	6,073	2.6	0.11	51.4	14.7	1.8
1996	7,184	3.3	0.13	65.9	16.9	2.2
1997	8,635	2.3	0.12	47.1	18.8	1.9
1998	9,389	2.0	0.12	56.3	19.3	3.2
1999	10,152	2.0	0.11	91.5	20.3	6.6
2000	10,512	2.3	0.12	114.2	20.9	8.3
2001	11,031	2.1	0.12	123.1	21.6	9.6
2002	10,278	2.1	0.11	118.7	20.0	9.3
2003	8,886	2.4	0.11	110.1	17.8	8.0
2004	8,129	2.7	0.11	115.6	16.3	8.4
2005	8,951	2.4	0.11	118.6	17.8	9.2
2006	9,901	2.6	0.12	127.6	19.9	10.1
2007	11,115	2.3	0.13	132.0	22.4	11.1
2008	12,328	2.6	0.14	147.2	24.8	12.4
2009	13,639	0.9	0.09	118.4	25.4	10.7
2010	14,259	1.2	0.13	140.3	27.7	14.6

From converting the emissions of other GHGs into CO_2 equivalent through the parameters presented in Chapter 7 of the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), Table 33 was drawn up.

Table 33 – Energy consumption emissions in the cement sector (Gg CO_2eq)

Source: Own elaboration based on MCTI (2015) and IPCC (2006)

Ano	Emissões de CO_2 (Gg CO_2)	Emissões de CH_4 (Gg CO_2eq)	Emissões de N_2O (Gg CO_2eq)	Emissões de CO (Gg CO_2eq)	Emissões de NO_X (Gg CO_2eq)	Emissões de NMVOC (Gg CO_2eq)	Total GgCO_2 eq
1991	6,585	6	32	77	-	66	6,767
1992	5,149	5	24	61	-	48	5,287
1993	5,131	6	24	65	-	47	5,273
1994	5,060	6	27	74	-	48	5,214
1995	6,073	7	29	81	-	54	6,244
1996	7,184	9	34	104	-	62	7,393
1997	8,635	6	32	74	-	69	8,816
1998	9,389	6	32	88	-	71	9,586
1999	10,152	6	29	144	-	74	10,405
2000	10,512	6	32	179	-	77	10,806
2001	11,031	6	32	193	-	79	11,341
2002	10,278	6	29	187	-	73	10,573
2003	8,886	7	29	173	-	65	9,160
2004	8,129	7	29	182	-	60	8,407
2005	8,951	7	29	186	-	65	9,238
2006	9,901	7	32	201	-	73	10,213
2007	11,115	6	34	207	-	82	11,445
2008	12,328	7	37	231	-	91	12,694
2009	13,639	2	24	186	-	93	13,945
2010	14,259	3	34	220	-	102	14,619

A comparison between the process emissions and the energy emissions of the cement subsector shows that there is a tendency for emissions to grow in recent years.

When analyzing the lime sector, its process emissions are shown Table 34, where the value of 5,950 $GgCO_2$ is observed for the year 2010.

Table 34 – Process emissions from the lime sector in Brazil (Gg CO_2)

Source: MCTI (2015)

Year	Calcitic Lime Emissions (Gg CO_2)	Magnesium Lime Emissions (Gg CO_2)	Dolomite Lime Emissions (Gg CO_2)	Total Emissions (Gg CO_2)
1990	2,660	629	399	3,688
1991	2,670	664	421	3,755
1992	2,869	660	419	3,948
1993	3,064	720	457	4,241
1994	3,027	655	416	4,098
1995	2,990	681	432	4,104
1996	3,056	729	463	4,248
1997	3,176	711	451	4,338
1998	3,021	686	435	4,141
1999	3,110	743	471	4,325
2000	3,950	647	411	5,008
2001	3,765	640	406	4,811
2002	3,941	621	394	4,956
2003	4,043	624	396	5,064
2004	4,347	709	449	5,505
2005	4,321	634	402	5,356
2006	4,363	640	406	5,410
2007	4,566	673	427	5,666
2008	4,583	678	430	5,690
2009	3,924	695	441	5,060
2010	4,803	702	445	5,950

For the analysis of the energy emissions of the lime sector, the detailed energy consumption based on CNI (2010) was used and it is shown in the Table 35. There is only this data source regarding detailed energy information for the sector.

Table 35 – Energy consumption and production in the lime sector (10^3 toe and 10^3 tonnes)

Source: Own elaboration based on CNI (2010)

Year	2001	2002	2003	2004	2005	2006
Production (10^3 tonnes)	6,300	6,500	6,600	6,500	6,987	7,057
Electric power consumption (10^3 toe)	8.13	8.38	8.51	8.38	9.01	9.10
Petroleum coke and fuel oil (10^3 toe)	323	333	338	333	358	362
Natural gas (10^3 toe)	129	133	135	133	143	144
Firewood and wood waste (10^3 toe)	129	133	135	133	143	144
Mineral coal mill (10^3 toe)	64	66	67	66	71	72

Based on the information in the previous table, it was estimated the average consumption per ton of lime produced for each of the energy sources. Thus, knowing that lime production in 2010 was 7,761 thousand tonnes, the energy consumption of each of the sources was calculated based on the average of the years shown in Table 35, resulting in the values presented in the Table 36.

Table 36 – Calculated values for the energy consumption in the lime sector in 2010 (10^3 toe and 10^3 tonnes)

Source: Own elaboration based on CNI (2010)

Year	2010
Production (10^3 tonnes)	7,761
Electric power consumption (10^3 toe)	10
Petroleum coke and fuel oil (10^3 toe)	398
Natural gas (10^3 toe)	159
Firewood and wood waste (10^3 toe)	159
Mineral coal mill (10^3 toe)	79

Finally, making use of the emission factors of each energy source, it is possible to determine their emissions Table 37.

Table 37 – Calculated energy emissions for the lime sector (Gg CO_2)

Source: Own elaboration

Ano	2001	2002	2003	2004	2005	2006	2010
Electric power consumption (Gg CO_2)	4.8	5.0	5.1	5.0	5.4	5.4	6.0
Petroleum coke and fuel oil (Gg CO_2)	1,182.8	1,219.5	1,237.8	1,219.5	1,311.0	1,325.7	1,456.5
Natural gas (Gg CO_2)	303.1	312.4	317.1	312.4	335.9	338.3	372.9
Firewood and wood waste (Gg CO_2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mineral coal mill (Gg CO_2)	253.5	261.5	265.4	261.5	281.3	285.2	312.5
Total (Gg CO_2)	1,744.3	1,798.4	1,825.4	1,798.4	1,933.6	1,954.6	2,147.9

It is possible to observe that the process emissions are more relevant in relation to the total emissions of the sector.

Finally, regarding the glass sector, its process emissions in 2010 reached a total of only 114 GgCO_2, according to the Third National Communication of Brazil to the UNFCCC (MCTI, 2015), as detailed in Table 38.

Table 38 – Process emissions in the glass sector (Gg CO_2)

Source: MCTI (2015)

CO_2 Emission by calcination in the glass production ($GgCO_2$)	1990	1995	2000	2005	2010
Calcination of limestone	55	53	74	95	93
Calcination of dolomite	12	11	16	21	20
Total	67	64	89	116	114

Energy emissions could neither be obtained directly from the Third National Communication nor indirectly through data from the National Energy Balance (BEN), where the glass production sector is not detailed. Therefore, a methodology similar to that presented for the lime sector was applied. Table 39 shows the historical energy consumption of the glass sector and its production. Using these values, it was possible to determine an average consumption per source (toe/tonnes of glass).

Knowing the glass production of the ensuing years (2007 to 2010), it was possible to extrapolate the consumption of energy using the historical database of the Table 39.

Table 39 – Energy consumption and production in the glass sector (10^3 toe and 10^3 tonnes)

Fonte: CNI (2010)

Fuel	Year, Energy Consumption (10^3 toe) and Production (10^3 tons)					
	2001	2002	2003	2004	2005	2006
Natural gas (10^3 toe)	295.4	380.5	423.1	465.3	469.9	481.9
Fuel oil (10^3 toe)	124.6	114.8	71.9	70.3	64.2	53.4
Liquefied petroleum gas (10^3 toe)	18.2	15.1	11.0	8.7	8.3	7.9
Electricity (10^3 toe)	99.2	116.0	114.4	122.8	122.8	122.8
Total (10^3 toe)	537.4	626.5	620.3	667.1	665.2	665.9
Production (10^3 tonnes)	2,071	2,412	2,389	2,571	2,561	2,566

The results of the extrapolation of energy consumption by source in the glass sector are shown in Table 40.

Table 40 – Projections of energy consumption and production for the glass sector (10^3 toe, 2007 – 2010)

Source: Own elaboration based on CNI (2010)

Fuel	Year, Energy Consumption (10^3 toe) and Production (10^3 tonnes)									
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Natural gas (10^3 toe)	295.4	380.5	423.1	465.3	469.9	481.9	432	389	441	485
Fuel oil (10^3 toe)	124.6	114.8	71.9	70.3	64.2	53.4	53	48	54	60
Liquefied petroleum gas (10^3 toe)	18.2	15.1	11.0	8.7	8.3	7.9	7	7	7	8
Electricity (10^3 toe)	99.2	116.0	114.4	122.8	122.8	122.8	112	101	114	125
Total (10^3 toe)	537.4	626.5	620.3	667.1	665.2	665.9	604	544	617	678
Production (10^3 tonnes)	2,071	2,412	2,389	2,571	2,561	2,566	2,326	2,095	2,375	2,611

Finally, by making use of the emission factors of each energy source, it is possible to determine the profile of energy emissions in the glass sector, shown in Table 41.

Table 41 – Calculated energy emissions for the glass sector ($GgCO_2$)

Source: Own elaboration

Fuel	Year and Emissions ($GgCO_2$)									
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Natural gas	694	894	994	1,093	1,104	1,132	1,014	913	1,036	1,138
Fuel oil	404	372	233	228	208	173	173	156	176	194
Liquefied petroleum gas	48	40	29	23	22	21	19	17	20	22
Electricity	59	69	68	73	73	73	66	60	68	75
Total	1,206	1,375	1,324	1,417	1,406	1,399	1273	1,146	1,300	1,429

B.3. Chemicals

In 2010, the Brazilian chemical sector reached a total process emissions of 3,488 Gg CO_2 equivalent, as explained in the Table 42.

Table 42 – Process emissions in the chemicals sector (Gg CO_2eq)

Source: Own elaboration based on MCTI (2015)

Year	CO_2	CH_4	N_2O	CO	NO_X	NMVOC	Total
1990	2,373	14.5	2,833	0.8	-	97.2	5,318
1991	2,161	14.4	3,567	1.1	-	90.9	5,834
1992	2,196	14.9	3,326	0.9	-	90.6	5,628
1993	2,422	16.7	4,280	1.3	-	101.9	6,822
1994	2,468	18.4	4,320	1.3	-	112.2	6,919
1995	2,548	18.2	4,622	1.4	-	115.1	7,304
1996	2,549	18.2	3,609	1.1	-	115.1	6,293
1997	2,690	20.5	3,212	0.9	-	123.2	6,046
1998	2,591	21.7	5,056	1.6	-	128.0	7,798
1999	2,861	23.0	5,032	1.6	-	137.5	8,055
2000	2,615	24.8	5,284	1.6	-	157.3	8,083
2001	2,314	23.6	4,306	1.3	-	149.2	6,794
2002	2,507	23.1	5,377	1.7	-	154.7	8,063
2003	2,720	24.6	4,937	1.6	-	166.1	7,849
2004	2,974	26.0	6,887	2.2	-	180.0	10,070
2005	2,954	25.8	6,050	1.9	-	179.7	9,211
2006	3,017	34.3	6,567	2.0	-	197.3	9,817
2007	3,054	35.0	779	2.2	-	206.8	4,077
2008	3,017	31.5	604	2.2	-	207.5	3,862
2009	2,733	32.6	268	2.2	-	218.2	3,254
2010	2,983	32.8	246	2.2	-	224.0	3,488

The energy emissions of the chemical sector are presented in the Table 43.

Table 43 – Energy emissions in the chemical sector (Gg CO_2eq)

Source: Own elaboration based on MCTI (2015)

Year	CO_2	CH_4	N_2O	CO	NO_X	NMVOC	Total
1990	8,606	2.2	31.8	46.4	-	9.2	8,696
1991	8,811	2.2	31.8	44.6	-	8.8	8,898
1992	9,080	1.9	26.5	37.4	-	8.1	9,154
1993	8,578	1.9	29.2	39.3	-	8.4	8,657
1994	9,114	2.2	31.8	43.2	-	10.3	9,201
1995	10,057	2.2	29.2	39.4	-	10.6	10,138
1996	11,493	2.2	29.2	32.1	-	8.4	11,565
1997	13,352	2.5	31.8	29.2	-	8.8	13,424
1998	12,343	2.8	29.2	28.1	-	8.8	12,412
1999	13,551	3.0	34.5	31.7	-	11.0	13,631
2000	13,942	3.6	34.5	32.1	-	12.1	14,024
2001	13,930	3.9	37.1	29.1	-	11.7	14,012
2002	14,161	4.7	39.8	28.0	-	12.1	14,245
2003	13,508	5.5	39.8	31.9	-	11.7	13,597
2004	14,353	6.3	45.1	32.8	-	12.5	14,450
2005	14,624	6.6	47.7	33.8	-	12.5	14,725
2006	14,880	6.9	47.7	34.7	-	12.5	14,982
2007	15,598	7.2	50.4	36.5	-	13.9	15,706
2008	14,283	7.2	47.7	34.4	-	12.1	14,384
2009	14,446	6.9	47.7	33.9	-	12.5	14,547
2010	13,847	6.9	47.7	35.4	-	12.5	13,949

When analyzing the relationship between energy emissions and process emissions, it is observed the discrepancy between these values and that the composition of the sector is mainly due to the energy emissions.

B.4. Pig Iron and Steel

The Pig Iron and Steel industry has the highest process emissions indices of the subsectors analyzed, reaching in 2010 the value of 39,794 $GgCO_2eq$, as detailed in the Table 44.

Table 44 – Process emissions in the Pig Iron and Steel sector (Gg CO_2eq)

Source: Own elaboration based on MCTI (2015) and IPCC (2006)

Year	CO_2	CH_4	N_2O	CO	NO_X	NMVOC	Total
1990	21,601	101	270	1,218	-	79	23,270
1991	26,118	86	257	1,052	-	71	27,583
1992	26,417	80	246	987	-	67	27,798
1993	28,206	87	268	1,078	-	74	29,713
1994	29,392	90	276	1,113	-	76	30,947
1995	30,130	83	265	1,031	-	72	31,581
1996	30,866	72	246	908	-	65	32,157
1997	32,521	75	260	948	-	69	33,873
1998	33,319	69	249	877	-	65	34,580
1999	31,680	79	265	980	-	71	33,075
2000	35,552	85	289	1,062	-	77	37,066
2001	34,845	80	276	1,002	-	73	36,276
2002	37,516	83	292	1,040	-	77	39,008
2003	38,683	95	318	1,171	-	85	40,352
2004	39,805	114	360	1,396	-	99	41,775
2005	37,509	112	347	1,363	-	96	39,427
2006	36,051	108	334	1,314	-	93	37,900
2007	39,422	111	352	1,360	-	97	41,342
2008	39,825	109	350	1,335	-	96	41,714
2009	31,690	64	233	799	-	61	32,846
2010	38,360	79	286	995	-	74	39,794

The energy emissions of this sector, recorded in CO_2 equivalent, are shown in Table 45, reaching in 2010 the value of 5,557 GgCO_2.

Table 45 – Energy emissions in the Pig Iron and Steel sector (Gg CO_2eq)

Source: Own elaboration based on BRACELPA (2011)

Ano	CO_2	CH4	N2O	CO	NOx	NMVOC	Total
1990	4,373	0.6	5.3	3.9	-	4.0	4,387
1991	4,565	0.6	8.0	4.2	-	4.4	4,582
1992	4,850	0.6	8.0	4.4	-	4.4	4,867
1993	5,070	0.6	8.0	4.6	-	4.8	5,088
1994	5,318	0.6	8.0	4.9	-	4.8	5,336
1995	5,387	0.6	8.0	5.0	-	4.8	5,405
1996	5,352	0.6	5.3	5.0	-	4.4	5,367
1997	5,201	0.6	5.3	5.0	-	4.4	5,216
1998	4,560	0.3	5.3	4.6	-	4.4	4,575
1999	4,268	0.3	5.3	4.6	-	4.0	4,282
2000	4,620	0.3	5.3	5.0	-	4.0	4,635
2001	4,470	0.3	5.3	4.9	-	4.0	4,484
2002	4,722	0.3	5.3	5.2	-	4.0	4,737
2003	4,796	0.3	5.3	5.2	-	4.4	4,811
2004	4,839	0.3	5.3	5.3	-	4.4	4,854
2005	5,297	0.3	5.3	5.8	-	4.4	5,313
2006	5,279	0.3	5.3	5.8	-	4.4	5,295
2007	5,733	0.3	5.3	6.0	-	4.4	5,749
2008	5,590	0.3	5.3	5.8	-	4.4	5,606
2009	4,322	0.3	2.7	4.6	-	4.0	4,334
2010	5,540	0.6	5.3	5.8	-	5.1	5,557

Thus, in 2010, the Pig Iron and Steel sector reached a total of 45,351 GgCO_2 equivalent.

B.5. Pulp and Paper

GHG emissions related to the industrial process for Pulp and Paper production are low when compared to other industrial sectors. The production of the chemical pulp, carried out mainly by the Kraft process, is an indirect GHG emitter, since during the preparation of the cellulose by the Kraft process, chemical reactions are source of CO, NOx and NMVOC emissions, as shown in the Table 46 that presents the industry process emissions converted into CO_2 equivalent.

Table 46 – Process emissions in the Pulp and Paper sector (Gg CO_2eq)

Source: Own elaboration based on BRACELPA (2011)

Year	CO	NO_X	NMVOC	Total
1990	31.6	-	48.8	80.4
1994	45.1	-	69.7	114.8
2000	58.5	-	90.2	148.7
2005	82.7	-	127.6	210.3
2010	114.7	-	177.1	291.8

Energy emissions are considerably more significant as shown in the Table 47.

Table 47 – Energy emission in the Pulp and Paper sector (Gg CO_2eq)

Source: Own elaboration based on MCTI (2015)

Year	CO_2	CH4	N2O	CO	NOx	NMVOC	Total
1990	2,464	2.8	103	400	-	29	2,999
1991	2,725	2.8	101	420	-	29	3,277
1992	3,120	3.3	114	493	-	33	3,763
1993	2,909	3.3	119	559	-	32	3,622
1994	2,954	3.3	130	599	-	33	3,719
1995	3,384	3.3	130	580	-	33	4,130
1996	4,013	3.3	122	609	-	30	4,778
1997	3,715	3.3	122	623	-	29	4,492
1998	3,956	3.9	146	696	-	35	4,836
1999	4,264	3.9	151	740	-	34	5,193
2000	4,320	4.1	159	760	-	37	5,,280
2001	4,086	4.1	159	756	-	40	5,045
2002	4,290	4.1	164	821	-	40	5,320
2003	3,993	4.7	183	945	-	46	5,171
2004	3,749	4.7	191	999	-	44	4,988
2005	3,840	5.0	199	1,058	-	47	5,148
2006	3,246	5.5	217	1,140	-	53	4,662
2007	3,529	5.8	228	1,212	-	56	5,031
2008	3,420	6.1	241	1,286	-	60	5,013
2009	3,372	6.3	254	1,364	-	63	5,060
2010	3,632	6.9	273,0	1,475	-	68	5,455

Annex C – Interactions of Industry with Other Sectors

This annex highlights the interactions between industry and other economic sectors in the context that institutional arrangements for carbon pricing in the industrial sector will necessarily interact with pricing instruments eventually applied to other sectors. In fact, a national mitigation policy would be more cost effective as more sectors get involved, which would allow the use of mitigation options with lower abatement costs. Thus, it is likely that the institutional arrangement of a carbon pricing system for the Brazilian industrial sector will be formulated, in an intersectorial way, including the sectors of fuels, electricity generation and agriculture, forestry and other land use (AFOLU). Although the evaluation of other sectors is not in the scope of this thesis, this annex briefly seeks to qualitatively analyze the interactions that may occur between the mentioned sectors, in a context of implementing an industrial CPI at the national level.

C.1. Interactions with Fuel Sector

Emissions in the industry can occur through industrial processes, in which the emission of GHG occurs as a consequence of chemical reactions present in industrial production processes, or through the combustion of energy vectors from fossil origin or biomass from deforestation. Thus, the interaction between the industrial sector and the fuel sector is evident, since in 2014, 38.6% of the industrial sector emissions originated in fuel consumption (MCTIC, 2016b).

The fuel sector encompasses oil exploration and production (E&P), oil refining and the production of biofuels. In the former case, pricing instruments are generally not used, as international experience shows, because of technical difficulties in doing so (ICAP, 2018). In the E&P sector there is a great degree of geological heterogeneity of the oil reservoirs. The specific energy consumption is dynamic, varying according to the evolution of exploration of the reservoir. That is, the geological characteristics and the maturity of the reservoirs imply different energy needs and variations in fugitive gas emissions. Therefore, pricing the emissions of the E&P process can be extremely complex and difficult to monitor, which makes it very difficult to implement a carbon pricing instrument. In terms of mitigation policy, in this case, there is the possibility of command-and-control instruments that can obtain abatement results using a simpler regulatory framework.

The refining sector can be regarded as an industrial plant, being actually treated as such by the National Accounts. The refining process consists of the conversion of petroleum into its derivatives, which are consumed by the industrial, transportation, building (residential, commercial, services and public sectors) and agricultural sectors.

It should be noted that international experience indicates a difficulty in attributing to the refining industry the responsibility of combustion emissions by the sectors that demand fuels. Firstly, the refining sector has no interference with the consumption of fuels and with the measures to reduce emissions from combustion of sectors external to it. Second, as the American attempt has shown, competition from imported petroleum derivatives may become a hindrance to the pricing system (MARCU et al., 2014). Therefore, a carbon pricing in the refining sector should be tied to the emissions related to the oil refining process and not to the burning of the fuels sold by the sector. Emissions in the refining sector, in turn, can occur both by chemical processes and by combustion for energy purposes.

Concerning the interaction of the refining sector with the industrial sector, the following possibilities are envisaged: (i) an ETS that includes the industrial and refining sectors, in which the total emissions related to the activities in each sector (process and combustion emissions); (ii) an ETS for industrial process emissions (including or not the refining sector), with combustion emissions being priced separately for a carbon tax. The advantage of the second option is that it can be aligned to a CPI in other sectors of consumption (transportation, buildings and agriculture) through the taxation of fuels, since these other sectors are too atomized to participate in a ETS.

Finally, with regard to the biofuels sector, there is a clear interaction with the food and beverage industry, more specifically with sugar production. In Brazil, according to ANP (2017), 64% of the distilleries are annexed distilleries, in which there is relative flexibility to produce ethanol or sugar, depending on the market conditions. In addition, in some industrial subsectors, the use of biofuels may be an alternative to abatement as substitutes for fossil fuels.

C.2. Interactions with Electric Power Sector

Although industry is an electricity consumer, unlike fuel consumption emissions, emissions from electricity consumed in the industrial sector are indirect. In other words, electricity emissions do not occur in the industrial plant itself, but in the thermoelectric plant where the fuel is burned. This difference greatly influences how the industrial sector interacts with the electricity sector, since the pricing of electricity emissions could not occur in the industrial plant, but in the power generation plant, which in turn would pass-through the costs on to industry (and other sectors) through higher electricity rates. It is clear, therefore, that a carbon pricing in the electric sector can affect the industry through higher electricity rates, regardless of the CPI used.

In some international experiences, such as EU ETS, California Cap-and-Trade and Australian CPM, the electricity sector is part of the permitting market, generating interaction among sectors through transactions in that market (ICAP, 2018). This possibility is difficult given the peculiarities of the Brazilian electrical system, which is a hydrothermal system coupled spatially and temporally. That is, the Brazilian electricity sector is a nationally interconnected system that requires centralized operation planning so that complementarities between power plants and regions can be used. The system is temporarily coupled since the operation at an instant in time implies the depletion (or not) of the reservoirs of the hydroelectric plants, thus affecting the availability of energy and the operation in the future. Centralized coordination of the operation, therefore, reduces the interference of thermoelectric plants in choosing their level of production and, thus, emission, affecting the ability to negotiate emission permits in a market.

However, other interactions between the electricity and industrial sectors in a context of carbon pricing can be glimpsed. Emissions linked to electricity generated in plants operating in the Free Contracting Environment (FCE), which is negotiated directly between agents, may eventually participate in an ETS together with the industrial sector. Finally, it is important to note that the industrial sector is also a producer of electricity, either through self-production or through cogeneration. To the extent that electricity is fully consumed by the agent of the industrial sector that generated it, the emissions are contained within the industrial sector and are priced according to the current instrument for the industry. However, once there is surplus electricity generation exported to the grid, it is necessary to integrate the pricing mechanisms of the two sectors.

C.3. Interactions with AFOLU Sector

Carbon offsets are investments in specific projects that reduce, avoid or hijack GHG emissions (WORLD BANK et al., 2018; CPLC, 2016). One of its main objectives is to create a flexible mechanism that allows a given sector to mitigate its emissions at a lower cost than it would have occurred through its own operations (for example, through transactions in an ETS or paying a tax on carbon emitted).

In general, offsets encourage mitigation projects to be undertaken in sectors that are not directly covered by CPI or that benefit from other government incentives, such as transportation, waste and agriculture, forestry, and other land use (AFOLU). In other words, these activities constitute opportunities for mitigation, reduction or sequestration of emissions, and it can generate carbon credits. These credits are then used as offset to the GHG emissions of the emitting sectors that have carbon reduction obligations, for example the industry. This is, therefore, a clear example of the polluter pays principle.

In Brazil, the agricultural sector is fundamental to the economy, not only for its economic role, but also socially and environmentally. It is important as a primary supplier of raw materials for the agribusiness sector, responsible for the marketing of its products. As PMR (2017) points out, when evaluating mitigation potentials in the agricultural sector, it is noted that some characteristics of agricultural and forestry activities show that the potential for reductions in emissions in this sector seems to be more in adjustments and changes in productive processes than, properly speaking, in the imposition of conventional policy instruments.

Numerous studies indicate that changes in the AFOLU sector could produce economically attractive reductions in GHG (mitigation) that would compete favorably with reductions from other sectors (ROCHEDO et al., 2018, KONRAD ADENAUER STIFTUNG and GVCES, 2018; CEBDS, 2018, 2017; GVCES, 2017; EPE, 2016; INSTITUTO ESCOLHAS, 2015; BNDES, 2010). An example would be biosequestration, which consists of capturing CO_2 and then storing carbon in the vegetation and soil. Such an alternative has significant potential in reforestation, tree cultivation on non-forest land (afforestation) and soil, especially in the rehabilitation of degraded soils.

Other opportunities for reducing emissions in this sector are possible and are even more consistent and necessary when observing that the Brazilian NDC aims to strengthen the ABC Plan, whose main goal is to promote the mitigation of GHG emissions in agriculture, proposing additionally the recovery of 15 million hectares of pasture degraded by 2030 and the increase of 5 million hectares of integrated crop-livestock-forest systems by 2030. According to PMR (2017), the total mitigation potential, considering the goals of the ABC Plan and the additional NDC commitments, is estimated between 239.4 and 294.4 million tCO_2eq.

With regard to the interactions between the industrial sector and the AFOLU sector, it is worth mentioning that the industry is a consumer of woody biomass, especially the Pulp and Paper and Steel sectors. Therefore, there is a clear interaction between the industrial sector and AFOLU. Mitigation measures that are based on reducing emissions through the replacement of fossil fuels by biomass should consider interactions with land use and forest policies. Thus, there are interesting opportunities for offset in this sector, in relation to the industry-AFOLU interaction, not only through planted forests (in relation to the Steel industry and Pulp and Paper), but also from the energy consumption in the AFOLU sector. The trade of carbon credits through offset would require special attention to the operational and methodological procedures - which is beyond the scope of this thesis -, but it is worth noting the wide international experience, including the Brazilian experience, within the scope of the Clean Development Mechanism (CDM), whose lessons would certainly support the development of offsets.