Carbon Tax vs Cap and Trade
The Market Concentration May Have the Last Word on Climate Change Policy:
An Evaluation for the Energy Sector in Colombia

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Master's Thesis

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Abstract:

This study reviews two approaches of carbon pricing to address climate change at the policy and economic level. It compares carbon tax with the cap and trade scheme in the energy industry of Colombia. The pros and cons of the two approaches are evaluated through focusing on the particular features of the Colombian context. These are: a highly concentrated market, with market power and heterogeneous productivity amongst firms. I conclude that the carbon tax is likely to be more effective and easier to implement at policy level.

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1. Introduction

The debate about climate change and economic growth may have reached its most heated point in October 2018, when the Economic Nobel Prize was awarded to the design of models and methods related to long-run development, economic growth, technological change, and climate change. The award not only encourages the continued development of the academic framework on the matter of economic instruments to address climate change but also emphasizes the importance of the governmental action and the imminent need for international cooperation.

The International Climate Change Regime was born in 1992 under the United Nations Framework Convention on Climate Change (UNFCCC), and since then has been working on addressing climate change through intergovernmental actions. Given that most of the actions achieved by this Regime regard with setting targets on the quantity of greenhouse gases (GHG) emissions have generally been referred to as a “quantity approach.” From the Kyoto protocol in 1997 to the Paris Agreement in 2015 countries have committed to reducing their GHG emissions without having defined policy instruments to achieve such a target, which becomes into a policy challenge itself.

According to Nordhaus, W. D. (2006), quantity approaches have a stranglehold on most environmental policies and thus, policymakers, environmentalists, and economists are accustomed to quantity constraints and targets in climate-change policy that the fundamental advantages of price-type approaches have been largely overlooked. He states that the effectiveness of these approaches depends on the curvature of the cost and benefit functions of reducing the GHG emissions. A fact frequently ignored on the design of public policy for climate change.

Carbon pricing is the cornerstone of the current climate change public policy with carbon tax and the cap and trade schemes as main economic instruments to address climate change. International cooperation and multilateral organizations, such as the World Bank and the Inter-American Development Bank, are promoting the allocation of the carbon price through a cap and trade scheme while the Nordhaus’ line of scholars encourages the implementation of the carbon tax.

In this study, I analyze the viability and practicability of implementing these economic instruments in Colombia, taking into account that, most of the economic sectors of Colombian economy have high informality levels; and those that do not have it, belong to concentrated markets with imperfect competition.

The Economic theoretical framework highlighted the pros and cons of the mentioned economic instruments when implementing in a context of imperfect competition and high market concentration with heterogeneous abatement costs (Anouliès, L.;2017). My analysis focuses on the period 2000 to 2012, where I find 32,21% of the GHG emissions are related to the energy supply. I used the marginal abatement cost of the energy supply to characterize the curvature of the cost function of reducing GHG emissions. I also employ the firms' market share by output and by added value to calculate the market concentration in the energy sector. I show that, given that energy supply has a high responsibility on the GHG emissions of Colombia, regulation on the energy sector to address climate change seems viable because it allows for costs to be passed down to consumers. I also show that the manufacturing industry of energy is highly concentrated which may distort, through lobby actions, the effectiveness of the regulation on the sector. Even more, one could speculate that it can explain the low tariff and the exemption of the coal in the current carbon tax.

My main result is that, given the abatement cost of the energy supply, the curvature of the marginal cost of reducing GHG emissions is positive and increasing. Therefore, according to Nordhaus, W. D. (2006), a price-type approach -the carbon tax- may be more efficient for Colombian context. Nevertheless, the market power on the manufacturing industry of energy may lead to an ex-ante non-compliance behavior (for the carbon tax) and extending the analysis to the cap and trade scheme, lack of enforcement (ex-post). Therefore, I recommend continuing implementing the carbon tax as the economic instrument to internalize the negative externality that GHG emissions impose on society, but with some changes, as a significant increase on the tariff and addition of the coal into the taxed fuels.

The rest of this paper proceeds as follows. Section 2 presents a scope into International Climate Change Regime, to provide context on the national and international institutional framework. Section 3 comprises the literature review focused on the theoretical discussion of the carbon price as a solution to the climate change market failure. Section 4 explains the employed data. Section

5 exposes the results from the analysis of the characterization of the GHG emissions in Colombia, the market concentration of the energy sector and the abatement cost of the firms of that sector. Section 6 synthesizes the mentioned results and proceed to the discussion between a carbon tax or a cap and trade as a better instrument for Colombia climate change policy. Section 7 refers to the conclusions and finally, Section 8 exposes the public policy recommendations.

2. Institutional Framework, Politics and Policies: A Scope into International Climate Change Regime

Uncertainties associated with global warming have extended the frontier in Economic Theory and the way it influences public policy. The discussion about climate change and economic growth may have reached its highest point in October 2018. The Committee for the Nobel Prize in Economic Sciences rewarded Paul Romer and William Nordhaus for their contributions to the Macroeconomic Theory. Nordhaus was recognized for integrating climate change into the analysis of economic activity in the long run. Whilst Romer was awarded for formalizing the endogenous economic growth, highlighting the importance of innovation, and the role of public policy to encourage it through the right incentives. The award was given three years after the signing of the Paris Agreement, where 195 States committed to contributing to climate change mitigation. The agreement set a target to keep global warming below 2°C in relation to the pre-industrialization temperature levels (IDEAM, 2017). According to The Committee for the Prize in Economic Sciences, the reward not only encourages the continued development of the academic framework, but also emphasizes the importance of the government's action and the imminent need for international cooperation (Nobel Prize in Economic Sciences; 2018).

To achieve the goals set out in the Paris Agreement, policy initiatives have moved toward a global accountability framework and the implementation of cost-efficient strategies. Therefore, multilateral banking and non-governmental organizations have joined the UNFCCC's cause to promote the allocation of a carbon price. Economic instruments such as Emissions Trading Systems (ETS) and carbon taxes have taken relevance on the discussion for efficiency, effectivity, and viability of setting a price for CO_2 emissions as a strategy to reduce GHG generation. As ETS and carbon taxes covered around $7gtCO_2eq$[1] in 2017, these economic instruments covered about 13% of global GHG emissions through a carbon price (PMR; 2016; Aiello, R. G., et al; 2018)

Related initiatives are now in more than sixty national or subnational jurisdictions [2], with some implementing more than one instrument in complementary ways. As shown on Map 2.1 and detailed extensively in Appendix A, two Latin-American countries exemplify that situation: Mexico and Chile (Aiello, R. G., et al; 2018). Each country started their climate actions with a carbon tax as part of fiscal reforms, and later introduced ETS as a more structured environmental policy. Colombia is on a similar path; with Law 1819 passed on the 29th of December 2016, a carbon tax was implemented to address climate change. Later, on the 27th of July 2018, Colombia also adopted a climate law, the first legal step for the implementation of an ETS. This law outlines a roadmap for the establishment of a National Program of Greenhouse Gases Tradable Emission Quotas, which can be understood as a normative pilot of what is likely to be a formal national ETS. The national target added to the features of context could determine the tradeoffs between choosing an ETS or a carbon tax, a combination of several instruments or stepwise implementation. Thus, there is not an absolute argument to state one instrument is superior to the others.

However, climate change concerns took a long process to leak in the political agenda, and to be positioned as a relevant topic in public policy. While Meteorologists, Climatologists and several other circles of scientists have been concerned about climate change and the effects of global warming for more than a century (Landsberg, 1945; Houghton, R. A., et al.; 2009), the participation of Economists in environmental policy is related to global governance arising in the 1990s (Nordhaus, W. D.; 2006). International Climate Change Regime was born in 1992 in Rio de Janeiro when the United Nations Conference on Environment and Development took place. This conference generated three international treaties known as the "Rio Conventions," amongst which included the UNFCCC (Zillman, J. W; 2009).

UNFCC is the result of 13 years of work that began in Geneva in 1979 with The First World Climate Conference (1st WCC), hosted by the World Meteorological Organization (WMO) in

[1] The contraction g*t* comes from gigatonnes which equivalents to 1x 10^9 tonnes or 1,000,000,000 tons of CO_2eq. Where *eq* represent equivalent, which means the mass of the emitted GHG gases measured by their equivalence in CO2 (carbon dioxide).
[2] By 2016 the ETS had been formally implemented in 35 countries, on four continents, 13 subnational regional schemes, and seven city level. Additionally, in five jurisdictions the ETS is in the implementation process and in 11 more on analysis and consideration, being Colombia one of those (ICAP, 2016).

collaboration with other organs of the UN system. After two weeks of discussions that highlighted the relationship between climate and socioeconomic development, the World Climate Conference Declaration was published as a first step on global governance over climate change (White, 1979; Keane, T.; 1982).

Along similar lines, The Intergovernmental Panel on Climate Change[3] (IPCC) was created on November 1st of 1988, as an assessment mechanism expert on climate change under intergovernmental supervision. The UNFCCC positioned the IPCC in the international spotlight by assigning the task to set up the methodologies for GHG accounting and later, to receive, check, and approve the national reports on the matter summited by countries (Zillman, J. W; 2009).

UNFCCC formally entered into force on March 21st of 1994 and currently has 197 members; the countries that have ratified it are called "Parties to the Convention" (Garcia; A. C; 2015; UNFCC, 1994). Colombia attended the Rio Convention and ratified it by Law 164 in 1994. Since then, Colombia has assumed rising commitments (e.g., conducting the measurement of GHG emissions following the IPCC methodology). As a participating party, Colombia has presented periodic reports, such as the National Communications on Climate Change, the Biennial Reports and the construction of National GHG Inventories, in addition to attending the annual Conference of the Parties (COP) (IDEAM, 2016). The first COP was held in Berlin in 1995 and is hosted in a different city each year.

Every COP has raised the formality and practicability of the climate discussion on the political agenda. Three COPs were particularly instrumental for the introduction of economic instruments as the main strategy of public policy to reduce GHG emissions:

The COP 3 generated the Kyoto Protocol, and with it, the first binding targets for GHG reduction for thirty-seven industrialized countries. Those countries were selected due to their responsibility for the GHG emissions resulting from more than 150 years of industrial activity. These nations were also selected as pioneers to assume action on global warming since they had the capacity and resources to generate technological changes. The Protocol entered into force on February 16, 2005

[3] In general terms, the IPCC work covers the measurement of the magnitude and chronology of climate changes, estimation of possible environmental and socioeconomic effects, and design of realistic response strategies.

and established the commitment to reduce - between 2008 and 2012 - at least the 5% of the GHG emissions produced in respect to the base year of 1990 (United Nations, 1998).

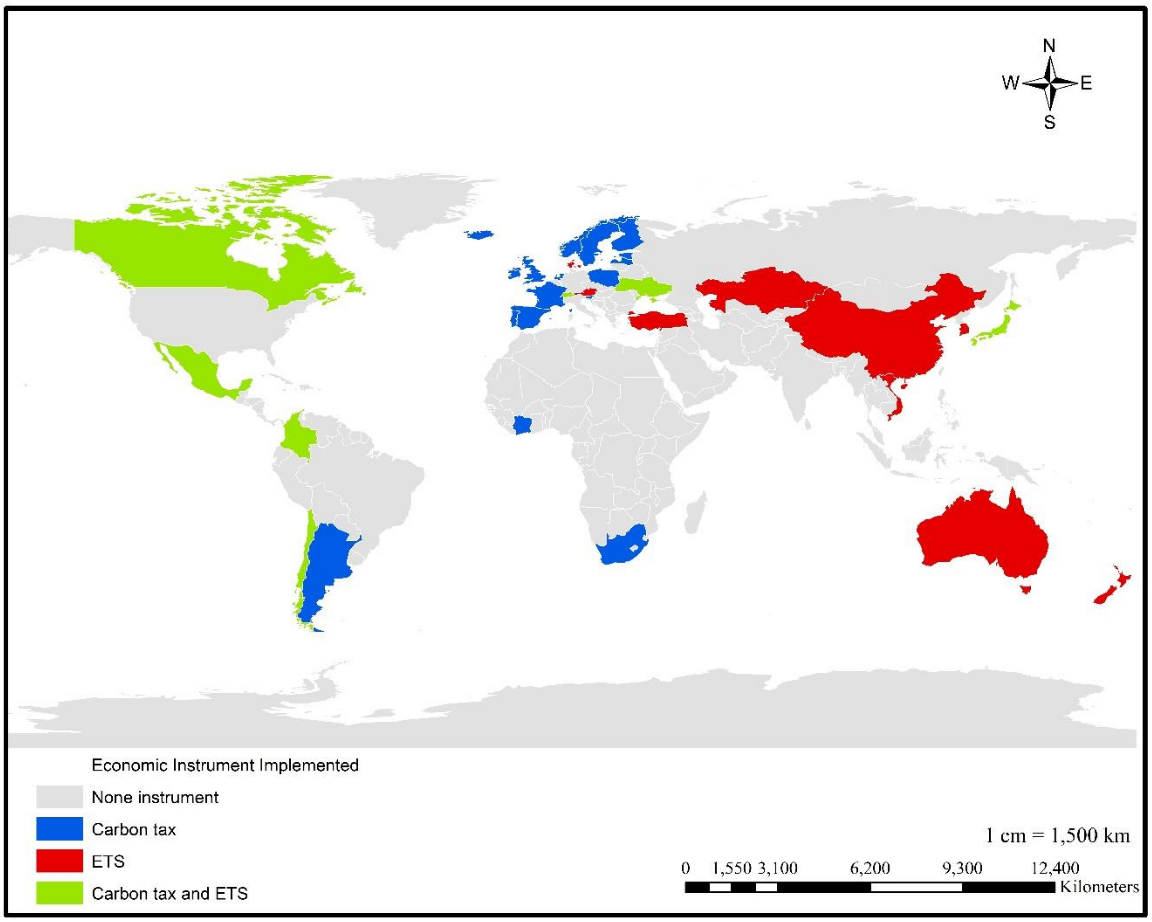
One of the most relevant conferences took place in Doha, fifteen years later. The COP 18 generated The Doha Amendment to the Kyoto Protocol, which not only modified some requirements applied to the first Kyoto period but added more members. All members assumed commitments to reduce at least 18% of their GHG emissions in a period between the start of 2013 to the end of 2020. The Doha Amendment is particularly relevant because it was the first step in incorporating interaction amongst countries to reach their emissions targets, which opened opportunities for market mechanisms and economic instruments. The three main mechanisms approved at that moment were: International Emission Trading (ETS), the Clean Development Mechanism (CDM) and Joint Implementation (JI). (United Nations; 2012).

Extensive negotiations took place between 2012 and 2015, with Parties agreeing they would set targets on contributions planned at the national level, which were termed as "Intended Nationally Determined Contributions" (INDCs). Colombia took the 2012 GHG inventory as the baseline year for its INDCs projections, committing to reduce twenty percent of its GHG emissions for 2030 (Garcia; A. C; 2015). In December 2015, the COP 21 took place in Paris, where all Parties put together their INDCs and committed to contributing to climate change mitigation. The Paris Agreement was signed, setting the goal to keep global warming below 2°C with regards to pre-industrialization levels (IDEAM, 2015).

Map 2.1 demonstrates that most countries have sought to achieve their INDCs through one or more economic instruments. As stated earlier, consequent Colombian legal arrangements are set, but the success of a carbon price design depends on the context and effectiveness of complementary policies. In compliance with Articles 4 and 12 of the UNFCCC, in 2017 Colombia submitted the National Inventory of GHG correspondent to the year 2012 and the whole historical series from 1990 to 2012. The inventory highlights that forty-four percent of Colombian GHG emissions come from the energy sector, with sixty-one percent of those emissions from the burning of fossil fuels (IDEAM; 2017).

The energy sector is one of the most formalized sectors of the Colombian economy, and therefore one of the easiest areas to regulate. Given that energy supply has a high responsibility on the GHG emissions of Colombia, regulation on the energy sector to address climate change seems viable because it allows for costs to be passed down to consumers. Nevertheless, in Section 5, I show that the energy market in Colombia is deeply concentrated, creating a challenge for policy design, under the risk of lack of enforcement, collusion, monopolistic power, lobbying efforts, and non-compliance.

Map 2.1: Countries implementing Carbon Pricing



Source: Author elaboration based on Carbon Pricing Dashboard Database – World Bank

3. Literature Review and Theoretical Framework

According to the economic perspective, climate change is a global public good (Nordhaus, W. D.; 2006). Economic theory considers global warming as an aggregate effect of GHG concentration on the atmosphere, and GHG accumulation as a negative externality that mainly derives from fossil fuels burning and energy production (Sims, R. E., et al.; 2003). Thus, climate change derives from an externality and its associated market failure (Stern, N; 2008). GHG emissions are not localized but rather global externalities. Even more challenging, these externalities are also intertemporal. For planet temperature, it doesn't matter who generates the GHG emission, when or where, but for policy and politics, it does. This is the reason why the heart of a good climate change policy must include a price on carbon and other greenhouse gases (GHGs) (Stern, N.; 2008).

The main goal for climate change regulation is to internalize the costs the externality imposes on society and to address them via incentives and economic instruments to reduce costs and increase efficiency (Cason, T. N.; 1995). Scholars have been highlighting that economic instruments are effective because those encourage technological change adoption rather than reduction on the aggregate amount of production (Konishi, Y., & Tarui, N.; 2015; Balistreri, E. & Rutherford, T.; 2012; Fischer, C.; 2011; Demailly, D., & Quirion, P.; 2008; Sartzetakis, E. S.; 1997). This is particularly relevant for efficiency in energy, transport and manufacturing sectors (Shapiro, J. S., & Walker, R.; 2015; Partnership for Market Readiness; 2016). Therefore, incentives not only should reduce GHG emissions but also accelerate technological change (Milliman, S. R., & Prince, R.; 1989).

Further, to reach GHG reduction amidst sustained growth amongst sustainable economies, research and development (R&D) are required. Romer, P. M. (1992) advocates for institutional rules, as a carefully designed patent system, to encourage innovation which also becomes into a responsibility of the climate change policy. Thus, GHG emissions are not the only externality whose costs are not properly taken into account, since knowledge spillovers are important as well.

Most climate change theoretical discussion reduces to how to deal with externalities without affecting the economies' growth path while technological change is encouraged. Analogously, one could reduce the theoretical debate to the Coasian versus the Pigouvian approach.

The concern about the harmful effect of firm's actions was exposed in *The Economics of Welfare* (Pigou, A.; 1920). The most traditional way to deal with an externality, Pigou argues, is levying via taxes or subsidies. Pigou justifies government intervention on the existence and persistence of the externality, whose costs the responsible firm does not have real interest on internalizing. Once the tax is levied, the increase in the firm's costs functions as a trigger to discourage the behavior or the activity that produces the externality, leading to a Pareto social optimal level.

The seek for such social optimal level encouraged Nordhaus, W. D (1993) to build the Dynamic Integrated Model of Climate and the Economy (DICE[4] model), the pioneer long-run macroeconomic analysis that integrates climate change. Three modules, economy, carbon circulation, and climate, make up a circular model that explains dependence between economy and climate. The economy module integrates GHG emitting and fossil fuel consumption as part of growth. The carbon circulation module shows how GHG emissions affect the atmosphere. The climate module focusses on how global warming affects economic growth. Consequently, Nordhaus suggests to tax fossil fuel, because consumers pay for the production costs, but not for its externalities. This research line has led to the interdisciplinary research of economics with environmental sciences which generated the Integrated Assessment Modeling (IAM).

Regarding public policy to address climate change, since there is no scientific evidence on the exact damage GHG emissions may generate, uncertainty is a central feature of climate-change policy. Despite uncertainty, scholars have worked on expressing such damage as a function of GHG emissions (Nordhaus, W. D., & Yang, Z.; 1996). Thus, the possible curvature of the mentioned damage function is used to analyze the marginal costs of reducing emissions, formally known as marginal abatement cost curves (MACC), on different scenarios.

According to Nordhaus, W. D. (2006): [...] "*the marginal costs of emissions reductions are highly sensitive to the level of emissions, while the marginal benefits of emissions reductions essentially*

[4] *DICE shorthand for a Dynamic Integrated Model of Climate and the Economy. The DICE model is a global dynamic optimization model for estimating the optimal path of reductions of greenhouse-gas emissions. The basic approach is to calculate the optimal path for both capital accumulation and reductions of greenhouse-gas emissions in the framework of the Ramsey (1928) model of intertemporal choice. The resulting trajectory can be interpreted as the most efficient path for slowing climate change given inputs and technologies; an alternative interpretation is as a competitive market equilibrium in which externalities or spillover effects are corrected using the appropriate social prices for greenhouse-gas emissions."* Nordhaus, W. D. (1993). Reflections on the economics of climate change. Journal of Economic Perspectives, 7(4), 11-25.

invariant to the current level of emissions reductions. […] Then the damage function is likely to be close to linear with respect to current emissions. Abatement costs, by contrast, are likely to be highly nonlinear as a function of emissions. This combination of relative nonlinearities means that emissions fees or taxes are likely to be much more efficient than quantitative standards or auctionable quotas when there is considerable uncertainty." (Nordhaus, W. D.; 2006; pg 14)

Nordhaus advocates for countries to penalize carbon emissions domestically with a carbon tax. This research line also advocates equalizing those domestics "carbon tax" across participating countries, to avoid customs tariffs or border tax adjustments among participants. This initiative is called harmonized carbon tax (HCT) because once the carbon tax gets equalized among countries could be considered harmonious at the global level (Nordhaus, W. D., & Yang, Z.; 1996). Due to the externality complexity, an efficient carbon tax should equalize the distortion between marginal carbon social cost and private marginal benefits, with appropriate discounting across space and time (Nordhaus, W. D.; 2006; Nordhaus, W. D.; 2014).

On the other hand, the Coase approach focuses on rights allocation, bargaining costs, and information gathering; proposing markets as a better option to solve externalities than courts or governmental intervention (Coase, R. H.; 1960). From this perspective, bargaining in the market not only reduces institutional costs but also leads the externality to find a price. Given that the atmosphere is both non-rivalrous and non-excludable it should be understood as a superior public good. Therefore, property rights over the atmosphere cannot be defined, transactions are not viable, and thus, it is not possible to find an optimum (Azqueta, D; 1994).

In the line of Coase, research in Environmental Economics shows that carbon markets may achieve a second best. A pricing and standards approach set a desirable goal, and seeks the economic instruments to achieve it; what is sought is not the optimal allocation but to assure a reduction in the level of damages via cost-effective strategies. When an environmental goal is set, economic instruments will be designed to achieve that goal at the minimum possible cost. The instrument must represent the usufruct or liability over the environmental goods and be subject to valuation, transaction, and regulation. Consequently, the instruments allow the externality price definition via relative prices and marginal costs (Baumol, W. J.; Oates, W. E.; 1971).

Whilst Pigouvian technic defines the basis for a carbon tax, pricing and standards define the basis for cap and trade.[5] In a cap and trade system, the quantity of emissions is set, with the price of allowances defined by the market, and allowances available via transactions. Alternatively, a carbon tax places a price directly on the externality generator, with the cost defined by policymakers, and quantities to be defined by the market. Pros and cons of each instrument are discussed in Section 6.

Dales, J. H. (1960) gave the name of "Market in pollution rights" for one of the first emission trading systems proposed in the literature. Pollution was understood as contaminants, and consequently encompassed much more than GHG emissions. The model was successfully implemented for the Acid Rain Program to control SO_2 emissions (Stavins, R. N.; 1998; Coggins, J. S., & Swinton, J. R.; 1996; Burtraw, D.; 1996; Montero, J. P.; 1997; Ellerman, A. D., & Montero, J. P.; 1996) and thus, became a cornerstone for CO_2 emissions reduction regarding climate change policy (Anouliès, L.; 2017; Liu, L., et al.; 2015).

Allocation of allowances is crucial in designing emissions trading systems. According to van Dyke, B. (1990), two allowance mechanisms are hotly debated: allocation via auction and allocation via grandfathering, which means to give permits or allowances to the firms for free based on historical output or emissions records (Cramton, P., & Kerr, S.; 2002; Boemare, C., & Quirion, P.; 2002). Grandfathering may undermine efficiency if firms anticipate future allocation strategy (Böhringer, C., & Lange, A.; 2005). Traditionally, free allowances are known as nonrevenue-raising instruments (NRRIs) (MacKenzie, I. A., & Ohndorf, M.; 2012) because they are freely allocated according to historical emissions or output and do not generate revenue to the government (Anouliès, L.; 2017). Arguments against historical emission allocation remain on empirical evidence of allowances becoming subsidies for some firms, leading to rent-seeking behavior and lobby actions (Cramton, P., & Kerr, S.; 2002; Hepburn, C. et al.; 2006), which could produce barriers to entry in a regulated sector (Böhringer, C., & Lange, A.; 2005; Demailly, D., & Quirion, P.; 2008). Historical allocations also discourage early action for emission reduction and technological change (Groenenberg and Blok, 2002; Boemare, C., & Quirion, P.; 2002). A drawback of output allocation is that firms can steer future endowments by a strategic behavior

[5] Cap and trade, tradable quotas, emission trading system (ETS), are all different names for a strategy based on the market transaction to set a price for the externality.

undermining the cost-effective structure of the cap and trade scheme (Böhringer, C., & Lange, A.; 2005; Anouliès, L.; 2017; Demailly, D., & Quirion, P.; 2008).

On the other hand, with allocation via auctions, polluters effectively purchase the right to pollute through the "revenue recycling" effect (Nordhaus, W. D.; 2006). This mechanism reduces the volume of assets available for lobbying and rent-seeking, which generates scarcity and competition from the first allocation moment, encouraging price equalization (Cramton, P., & Kerr, S.; 2002; Hepburn, C. et al.; 2006). To achieve the carbon cap, Cramton, P., & Kerr, S. (2002) suggest a standard ascending-clock auction, similar to Treasury debt sales. The auction should be made upstream to minimize administrative cost. At the same time, to maximize liquidity, allowances should be fully tradable in the secondary market. Tradable allowance auctions, as well as carbon taxes, are known as revenue-raising instruments (RRIs) because they may generate revenue for the government (MacKenzie, I. A., & Ohndorf, M.; 2012).

In the debate of market-based regulation mechanisms a hot topic focuses on the instruments that work better to reduce GHG emissions: those that allow rent creation and capture, or those that do not allow it. According to Anouliès, L. (2017), the initial allocation of the emission allowances modifies the market structure, and firms' heterogeneity magnifies that effect. By using a Melitz model (Melitz, M. J.; 2003), Anouliès provides theoretical evidence of allocation effects on a scenario of imperfect competition, with heterogeneous firms' productivity and free entry and exit to the market. In one hand, setting a cap for GHG emissions defines environmental quality but has no effects on firms' profits or decisions to entry or exit the market. On the other hand, the share of free allowances allocated has no effect on environmental quality but leads to resource reallocation through the most productive firms, which affects the market composition.

Based on this reasoning, Najjar, N., & Cherniwchan, J. (2018) estimates the effects of Canadian environmental policy on the nation's manufacturing sector, focusing on firm's entry and exit, resource reallocation, and cleaner technology adoption. They found policy effects change within sectors according to abatement costs, which are related to heterogeneity across firms' productivity. Environmental goals either required technological changes or reductions in the activities that generate the damage. Canada's empirical evidence shows that firms choose the first option.

Scholars haven't defined the answers for climate change policy but have developed methodological tools to evaluate options. Following the discussion between the carbon tax and the cap and trade as mechanisms to internalize the costs GHG emissions impose on society, my work analyzes the viability and practicality of implementing one of these in Colombia. Specifically, I explore the role that high concentration inside the energy market of Colombia might have on selecting the best mechanism. The energy sector is interesting since it is characterized by imperfect competition, high market concentration, and heterogeneous abatement costs.

I found that heterogeneity amongst the abatement costs makes the marginal abatement cost positive and increasing. While the marginal benefit of reducing GHG emissions is positive but eventually constant or decreasing. According to Nordhaus, W. D. (2006): *"If the curvature of the benefit function is small relative to the curvature of the cost function, then price-type regulation is more efficient"* (Nordhaus, W. D.; 2006; pg 13). Therefore, and leveraging my arguments on this idea and the evidence I will show in the upcoming sections, I would recommend the carbon tax as the best mechanism for the energy sector of Colombia.

Regarding carbon tax implementation I found that, through lobbying, the market concentration may affect the reach of the right tariff to fit the target. Such distortion not only affects the effectiveness of the instrument in relation with the objective of reducing emissions. But also makes hard to match the domestic carbon tax with the global carbon tax. Therefore, lobbying may represent an ex-ante non-compliance behavior to the carbon tax objective.

I found another disadvantage of the carbon tax. Since it is a levy charged at fossil fuel sell for combustion, it does not bear any relation to an economically oriented strategy to encourage technological change. In the sector, such technological change would mean improvements on the production processes which represents benefits for the firms and reduction on fugitive emissions.

Based on the stated results for the carbon tax I analyze the effect of the mentioned characteristics of the energy sector on the viability of implementing a cap and trade scheme. I leverage on Anouliès, L. (2017)'s theoretical work to study whether the cap and trade scheme may lead to intra-industry reallocation, monopolistic power, and institutional inefficiencies, finding that the effect may be even more costly.

As I discuss in Section 6, the implementation of a cap and trade scheme requires policy decisions and the construction of institutional architecture. The concentration of the market may not affect the decisions but to push for allocating the allowances via grandfathering on a rent-seeking behavior. Regarding allowances allocation, I found the problem is not the mechanism used, but the probability to participate in the secondary market with any of those. The reduced number of firms in the sector and the lack of required transactions amongst them explains the low participation. Without an active secondary market, the cap and trade scheme loses its purpose, and reduces itself to an ex-post action of non-enforcement.

4 Data and Information Sources

The purpose of this study is to analyze the best economic instrument for carbon pricing GHG emissions in Colombia. I use three data sets: INGEI[6], EAM[7], and the abatement cost estimations, to characterize the GHG generation in Colombia. I also employ which defined in Law 1819 of 2016 -the carbon tax law- and in Law 1931 of 2018- the climate change law- the first legal step for the implementation of a cap and trade scheme. The objective of implementing a carbon price is to achieve the country's target on climate change. Thus, I analyze the viability and practicability of continue implementing the carbon tax or rather change to a cap and trade scheme, known as Emission Trading System (ETS[8]).

The data allows me to characterize the GHG generation and the proportion stemming from fossil fuel combustion. Since the current carbon tax was implemented to tax fossil fuels combustion, and thus to cover its GHG emissions, my analysis focuses on energy supply. The Colombian energy supply comprises the electrical generation in the interconnected national system- SIN[9]-, the

[6] INGEI is the Spanish acronym for National Inventory of GHG *"Inventario Nacional de Gases Efecto Invernadero".* An inventory of emissions and removals of Greenhouse Gases (GHGs) is a report, delimited in a period of time and space, of the amount of GHG emitted directly into the atmosphere as a result of human activities and removals by carbon sinks, such as forests, crops or grasslands (IDEAM & PNUD; 2016).

[7] EAM is the Spanish acronym for Annual Manufacturing Survey "*Encuesta Annual Manufacturera"*

[8] Another name for a cap and trade scheme of GHG emissions.

[9] SIN is the Spanish acronym for *Sistema Interconectado Nacional*

electricity generation in non-interconnected areas -ZNI[10]-, oil, gas, and coal, sources of GHG emissions along different production processes and the domestic use of energy.

To analyze the generation of GHG emissions in Colombia, I use the 2012 National Inventory of Greenhouse Gases (INGEI), which contains the updated historical data series from 1990 to 2012. An improvement of this INGEI version is that the results are ordered in accordance with the four groups stipulated by the 2006-IPCC methodology, while emissions are also disaggregated by the eight sectors of the Colombian economy. The 2006-IPCC establishes a methodology for accounting GHG emissions and removals into four major groups according to their origin: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and other Land Uses (AFOLU), and Waste. In parallel, the economic sectors of Colombia used by the IDEAM[11] to group GHG emissions and removal are Mining and Energy, Transportation, Commerce Manufacturing Industry, Residential, Agriculture and Livestock, Forestry, and Sanitation.

Table 4.1: IPCC Energy group and the economic sectors of Colombia

IPCC Groups			**Economic sectors of Colombia**
1. Energy General Methodology: 2006 IPCC Guidelines for national greenhouse gas inventories, Volume 2 - Energy (chapters 1 to 4)	1. A Fuel burning activities Emissions generated by the burning of fossil fuels and biomass in any kind of machine designed to produce the heat or mechanical work required to carry out different activities or processes in different sectors. Each of those is contemplated among subgroups 1.A.1 through 1.A.4	1. A.1 Energy industries	Mining and energy
		1. A.2 Manufacturing and construction industries	Manufacturing Industry
		1. A.3 Transportation	Transportation
		1. A.4 Others sectors	Commerce
	1. B Fugitive emissions from the manufacture of fuel Emissions generated in the extraction, processing, production, storage, and distribution of the fuels. It includes the emissions spontaneously released into the environment and those generated by the burning torch. These emissions are divided into two main subgroups 1.B.1 and 1.B.2	1. B.1 Solid fuels	Residential
		1. B.2 Non-solid fuels; Oil and Natural gas	Agriculture and Livestock
	1.C Transport and storage of CO2 No evidence of this process in the country at the time		Forestry
			Sanitation

Source: Author elaboration based on 2012-INGEI- IDEAM

[10] ZNI is the Spanish acronym for *Zonas No Interconectadas*

[11] IDEAM is the Spanish acronym for *Instituto de Hidrología, Meteorología y Estudios Ambientales* institution in charge of the construction of the INGEI

As stated earlier, I mostly focus on the data related to Colombia's energy supply. Regarding the IPCC methodology, the focus is on the group Energy. Table 4.1 shows that, in this group, emissions are reported from the burning of fuels, and fugitive emissions generated in the processes of different sectors of the Colombian economy.

To analyze the market of energy and characterize firms related to energy supply, I employ data from the EAM, a panel dataset built by the National Administrative Department of Statistics (DANE). The survey contains confidential information on the firms that belong to the Colombian manufacturing industry, classified by their productive activity according to the International Standard Industrial Classification of all Economic Activities (ISIC). I worked with 248 observations focusing on the value added per firm and its output.

To analyze the heterogeneity among firms of the energy sector, I use the abatement cost curves of the energy supply, which constitute a proxy over the technology standards inside the industry. This data comes from the study "Sectoral Analytical Products to Support Decision-making on Mitigation Actions at a Sectoral Level," carried out in 2014 by the Study Group of Urban and Regional Sustainability from Universidad de Los Andes. Such a study focused on the estimation of marginal abatement cost curves (MACC), reported the marginal cost of reducing GHG generation in the energy supply of Colombia during the period from 2010 to 2040 (UniAndes; 2014).

See Appendix B for more details on the data sources and further information about the survey and the studies construction, which facilitates an upstream approach, relevant to the analysis targeting the sector.

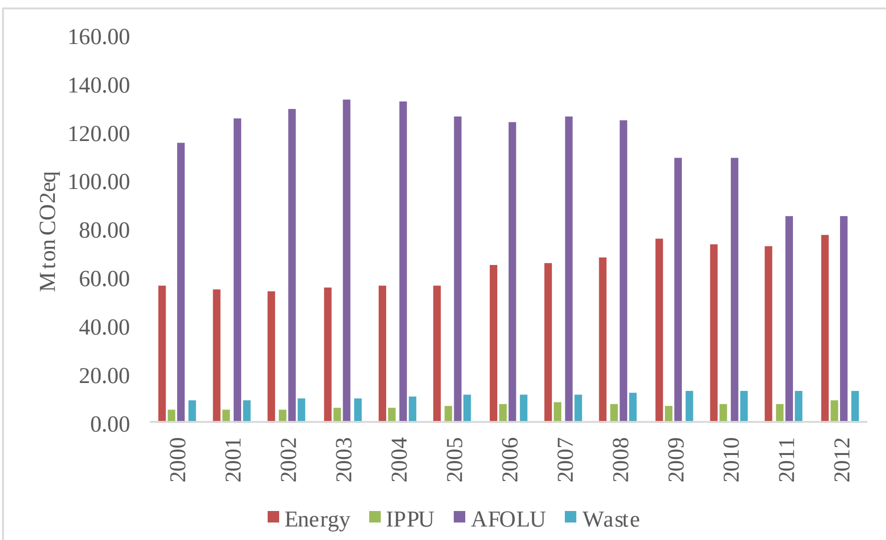
5. Energy Supply Characterization – Results

As stated before, Colombia has implemented a carbon tax as part of climate change policy instrument since December of 2016. The basic intuition behind the levied fossil fuel consumption charges is to convey their cost to the rest of the economy and to cover the higher amount of GHG emissions. In this study I compare the possibilities of implementing a carbon tax versus implementing an ETS as Colombian climate change policy. The viability and practicability of these economic instruments depend on the characterization of GHG emissions generated in Colombia; their origins and projected trends.

I use the 2012-INGEI with three main purposes. First, to analyze the participation and trend of CO_2eq emissions from fuel burning and fugitive emissions among the total amount of Colombia GHG emissions. Second, to know the distribution of the GHG emissions among the Energy sub-groups, which leads me to know the distribution among activities and fuels. Third, to analyze the distribution of the GHG emissions among the economic sectors as the result of the energy consumption.

In the period of analysis, I find that GHG emissions from the energy group from IPCC methodology represent 27.07% to 42.03% of Colombia's emissions, with an average of 64.34 Mton of CO_2eq per year that has an increasing trend.

Graph 5.1: GHG emissions by IPCC groups

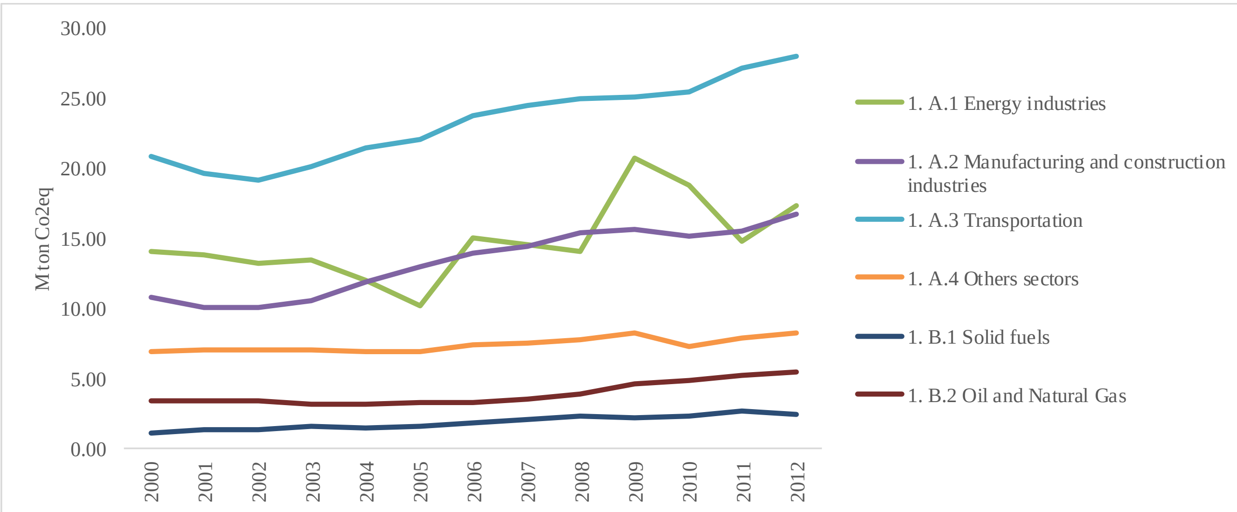


Source: Author calculation based on 2012-INGEI- IDEAM

The 2006-IPCC establishes a methodology for accounting GHG emissions and removals into four groups according to their origin: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and other Land Uses (AFOLU), and Waste

Graph 5.2 shown the subgroups of the Energy group as emitters amongst the group. I found transportation subgroup to have the highest responsibility for GHG emissions resulting from the burning of fuels, followed by the energy industries while fugitive emissions from solid fuels (coal) are the lowest.

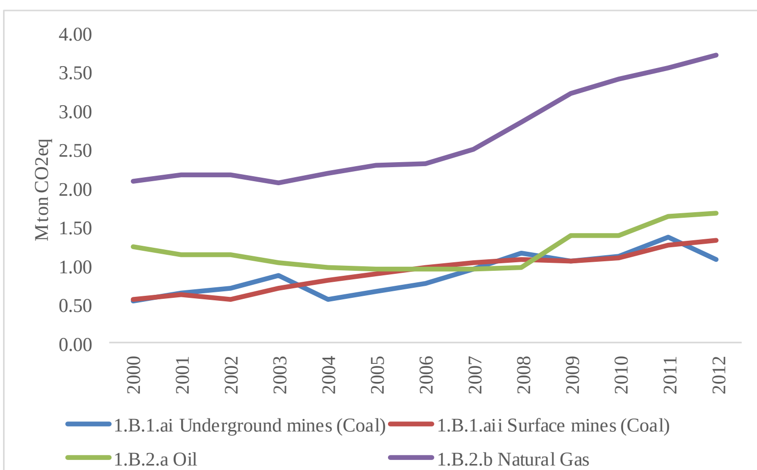
Graph 5.2: GHG emissions by IPCC Energy sub-groups



Source: Author calculation based on 2012-INGEI- IDEAM

As shown in Table 5.1, the emissions generated by the burning of fossil fuels and biomass in any kind of machine designed to produce the heat or mechanical work required to carry out different activities or processes in different sectors represents the major percentage of the GHG emissions from the energy group. Consequently, fugitive emissions from the manufacture of fuel never represented more than 11% of the energy group emissions. As is shown in Graph 5.3 amongst the different fuels of the Energy group, natural gas is the greatest emitter of fugitive emissions.

Graph 5.3: GHG emissions by Fugitives sub-groups (1.B)



Source: Author calculation based on 2012-INGEI- IDEAM

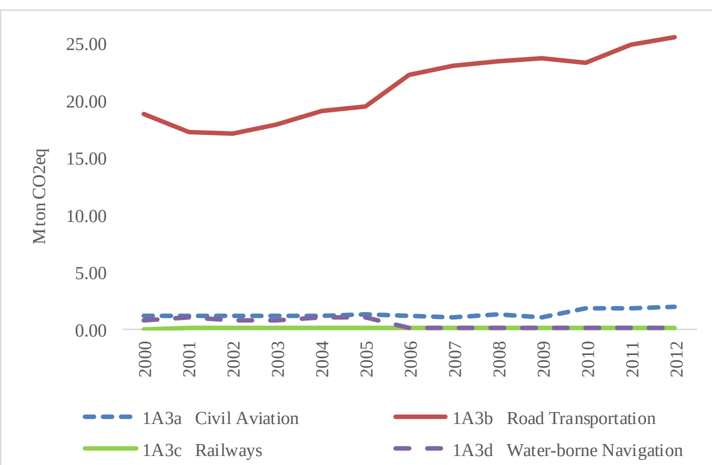
Table 5.1: GHG emissions by IPCC groups

Year	1. Energy Mton of CO2eq	1. A Fuel Combustion Activities Mton of CO2eq	1.A percentage	1. B Fugitive emissions from fuels Mton of CO2eq	1.B percentage
2000	56.99	52.54	92.19%	4.45	7.81%
2001	55.07	50.45	91.62%	4.61	8.38%
2002	54.12	49.52	91.50%	4.60	8.50%
2003	55.82	51.10	91.55%	4.72	8.45%
2004	56.78	52.22	91.96%	4.56	8.04%
2005	56.87	52.06	91.54%	4.81	8.46%
2006	65.13	60.10	92.29%	5.02	7.71%
2007	66.38	60.92	91.77%	5.47	8.23%
2008	68.24	62.15	91.08%	6.09	8.92%
2009	76.36	69.60	91.15%	6.75	8.85%
2010	73.63	66.60	90.44%	7.04	9.56%
2011	73.00	65.18	89.29%	7.82	10.71%
2012	78.02	70.21	89.99%	7.81	10.01%

Source: Author calculation based on 2012-INGEI- IDEAM

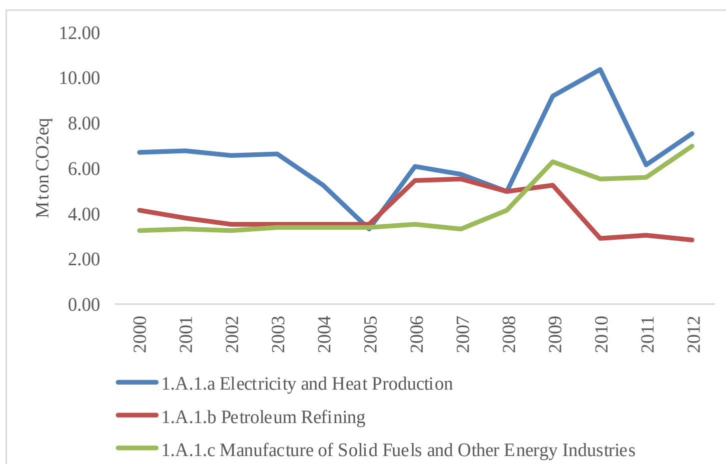
Amongst the subgroups of the Energy group, I found transportation to have the major responsibility for GHG emissions resulting from the burning of fuel. Within the transport subgroups, road transportation generates about 92% of the GHG emissions, as highlighted in Graph 5.4. As stated earlier, the energy industries are the second largest emitter amongst the energy group. Graph 5.5 shown a deeper distribution amongst such industry, where I found the electricity and heat production to have the major responsibility for GHG emissions.

Graph 5.4: GHG emissions by Transportation sub-groups (1.A.3)



Source: Author calculation based on 2012-INGEI- IDEAM

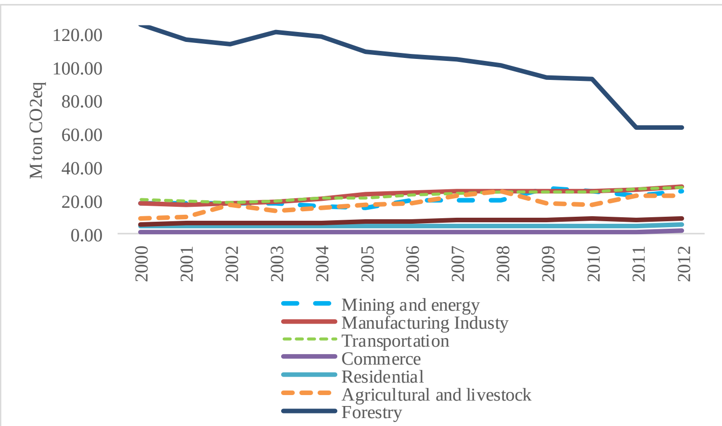
Graph 5.5: GHG emissions by Energy Industries sub-groups (1.A.1)



Source: Author calculation based on 2012-INGEI- IDEAM

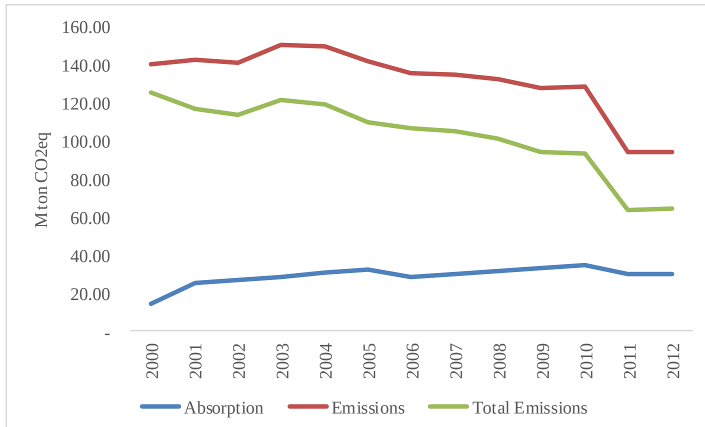
Respect to the economic sectors I found that the higher amount of GHG emissions stem from the forestry sector, about 34.62% in 2012; improvement respect to 2000 when the proportion was 61.47%. Such a result may be explained through the reforestation programs, leading to a reduction on the GHG emissions and an increase in the GHG absorption as shown in Graph 5.7. Regarding energy consumption, the higher emitter sectors are transportation and the manufacturing industry, while the sector with lower emissions is commerce.

Graph 5.6: GHG emissions by Economic sectors



Source: Author calculation based on 2012-INGEI- IDEAM

Graph 5.7: GHG emissions and absorption on Forestry sector



Source: Author calculation based on 2012-INGEI- IDEAM

The presented results show that energy supply is highly related with the GHG emissions generated by industrial manufacturing, transport activities, and energy production and consumption. Those results lead me to confirm that economics instruments levied towards energy supply may cover an important proportion of the national emissions (at least, of those that come from formalized sectors and thus, those that are a subject of regulation).

After the analysis of GHG generation in Colombia, I focus on the structure of the manufacturing industry of energy. Market power and technology standards are essential for carbon pricing, because the firms of this industry may become regulated actors. I use the EAM data to map the competitiveness of the industry through the construction of an HHI. The HHI is a measure of the market concentration of a certain industry. The index expresses the weight of the market share as a proportion of the market power and level of competitiveness among the industry.

$$HHI = \sum_{i=0}^{N} S_i^{\,2}$$

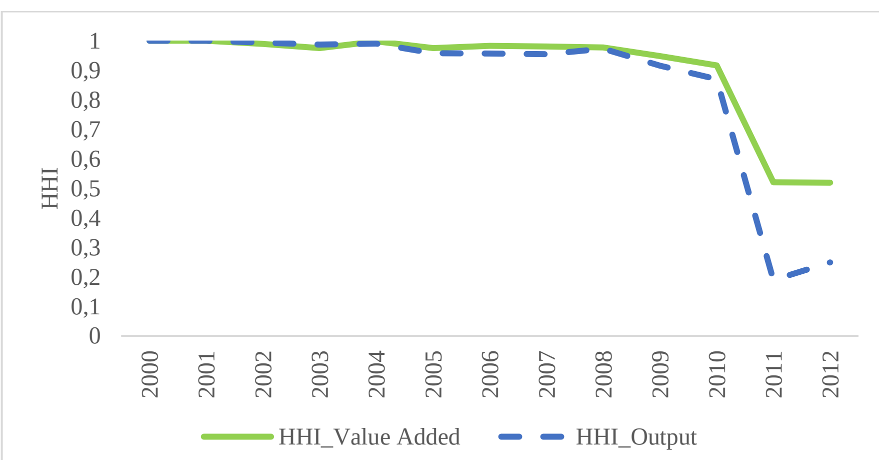
In Equation 5.1, S_i refers to the percentage market share that the companies held in the given industry, and N is the number of firms. The HHI ranges from 1/N (least concentrated) to 1 (most concentrated), in which case only one company operates the industry. According to antitrust laws, a low degree of concentration means that the industry is closer to a perfect competition scenario, whereby an HHI below 0.01 indicates a highly competitive industry. Table 5.2 illustrates the classification.

Table 5.2: GHG emissions by IPCC groups

HHI < 0.01	Highly competitive
0.01 < HHI < 0.15	Low concentration
0.15 < HHI < 0.25	Moderate concentration
0.25 < HHI < 1	High concentration

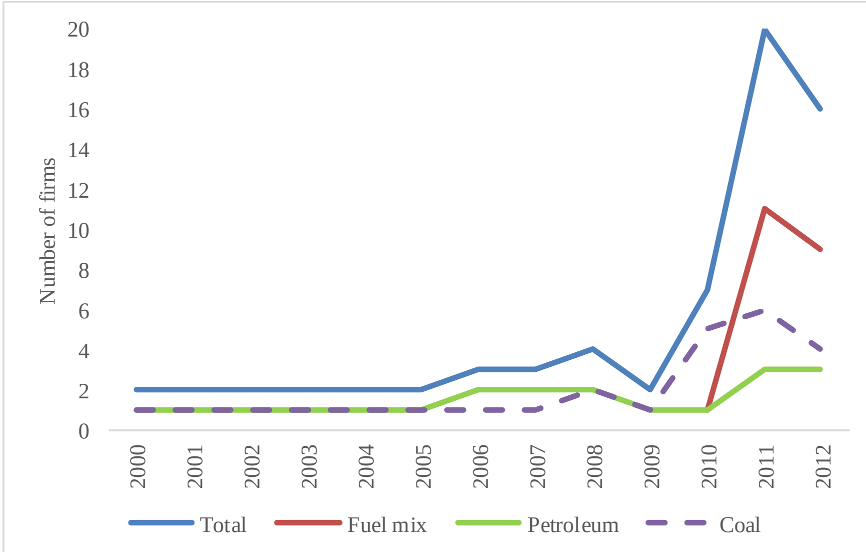
To calculate the HHI, I used firm market share by output and by added value. As shown in Graph 5.7, the HHI in the studied period is always higher than 0.18. Before 2010, the HHI for both output shares and value-added shares was even higher, with values greater than 0.8. The concentration decreased in 2010 thanks to the entrance of mix fuel activity firms (ISIC 2323/1922). Despite these changes, the post-2010 results indicate that the manufacturing industry of energy remains highly concentrated and there are few firms with relevant market power. This result is consistent with the number of firms that set up the industry of coal, oil, natural gas and fuel mix, which is shown in Graph 5.8.

Graph 5.7: Herfindahl-Hirschman Index for Energy manufacturing industries



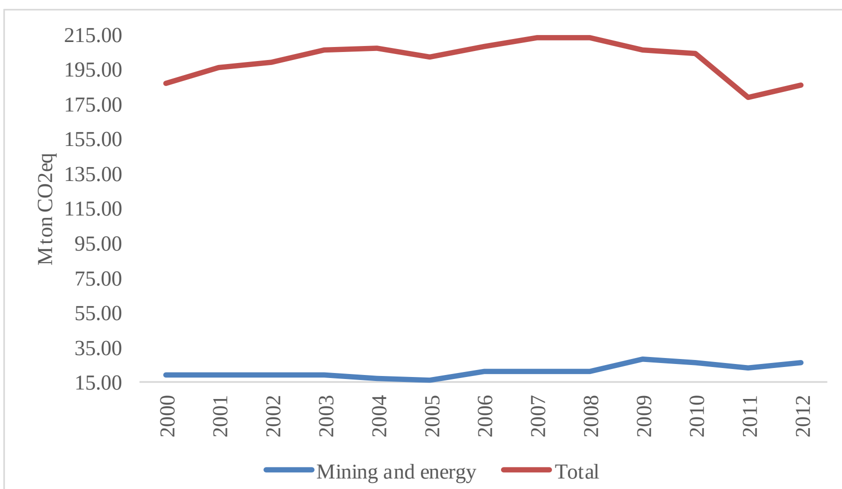
Source: Author calculation based on EAM - DANE

Graph 5.8: Number of firms in Energy manufacturing industries



Source: Author calculation based on EAM - DANE

Graph 5.9: Trends of GHG emissions Total and Energy sector



Source: author calculation based on 2012-INGEI- IDEAM

As stated above, at this point I have used the 2012 INGEI and the EAM survey data set to characterize the GHG generation in Colombia. According to Nordhaus, W. D. (2006) in order to take decisions between price-type regulation and quantity-type regulation is relevant to bear in mind the structure of GHG reduction function. While this issue has received little attention in public policy design, Colombia counts with the information to enhance policy discussion using the mentioned theoretical statement. Therefore, to aboard the structure of the GHG reduction cost function, I use the MACC.

The cost of reducing GHG emissions depends on the productivity of the firms and the employed technologies in the whole economy. Given that I found energy supply is responsible for a high proportion of GHG emission I use the MACC of energy supply calculated by UniAndes (2014). Since I also found out the energy market in Colombia is highly concentrated, I might assume an upstream regulation is viable. Therefore, I am interested in characterizing the homogeneity (or heterogeneity) level among firms of the sector to analyze this feature in the viability of each instrument implementation.

For concreteness, the homogeneity or the heterogeneity of the productivity of the firms would give me an intuition on the diversity of technologies implemented in the energy industry. Each technology has an associated cost of reducing GHG emissions generated. The cost of reducing such emissions is the abatement cost. Therefore, the marginal abatement cost curve of energy supply allows me to characterize the curvature of the marginal cost of reducing GHG emissions related to the energy supply.

The results from UniAndes (2014) study of energy supply are presented for SIN, ZNI, oil, gas, and coal. For SIN, they show abatement potential for up to 63 Mtons of CO_2eq during the analyzed period (2010-2040), with costs ranging from 13 USD to 8 USD per reduced ton.

Since SIN is primarily composed of hydroelectric power generators (64%), its technology is relatively clean and homogeneous (according to the capacity) with high abatement costs. Nevertheless, their projections demonstrate that climate variability and increasing restrictions on construction of medium and large hydroelectric power plants leads to a scenario where this kind of energy will have reduced participation in Colombia's energy supply in future years. Therefore, the study shows an increase in the CO_2eq emissions associated with the increase in thermal generation share, which may increase the oil, gas, and coal demand. According to "*Projection of the Demand for Electric Power*" (UPME, 2013) the mitigation scenarios consider the expansion of the required capacity using wind power, geothermal and cogeneration with biomass, rather than the traditional fuels, which could lead to a relevant heterogeneity in this sector.

According to the UniAndes 2014 study, 92% of ZNI electricity is generated with diesel, which makes the production more homogeneous and allows replacement of diesel by renewable sources in about 70% of municipalities. Such replacement could reduce 2 Mton CO_2eq with an abatement cost of -16USD/ton CO_2eq, 71USD/ton CO_2eq or 98USD/ton CO_2eq depending on the replacement source.

With regards to oil, gas, and coal, the study projection calculates the cumulative emissions between 2010 and 2040 to reach 870 Mtons of CO_2eq; with 570 Mtons of CO_2eq stemming from the oil and gas subsector and 300 Mtons of CO_2eq from the coal subsector. The incorporation of non-conventional resources, oils of lower quality and the use of refineries in their maximum capacity, explain that result, which requires the implementation of energy efficiency measures and optimization of processes, with the co-benefit of reducing GHG emissions in the different processes. Fifty percent of the options represent savings compared to the reference scenario, potential savings come from energy recovery, reduction in energy consumption or increases in production rates. The mitigation potential identified for the oil, gas and coal subsectors is 138 Mtons of CO2eq, equivalent to 16% of the accumulated emissions between 2010 and 2040 for the reference scenario.

The referenced scenario exposes that the energy supply of Colombia is produced through different technologies that require different fuels and thus, have different abatement cost. A firm from the energy sector may have diverse production processes, each one with its own abatement cost; some are positive while others are negative (savings), inherent to the heterogeneity of the sector.

Therefore, the MACC from the energy supply comes from negative to positive values, and thus the curvature is highly nonlinear as a function of emissions. This is how I found that heterogeneity amongst the abatement costs of the energy supply makes the marginal cost of reducing the GHG emissions positive and increasing.

6. Policy Discussion Carbon Tax vs Cap and Trade

As stated in Section 2, legal arrangements to implement a carbon price are set in Colombia. The carbon tax was implemented with Law 1819 passed on the 29th of December 2016 while the climate law, adopted on the 27th of July 2018, introduced the first legal step for the implementation of an ETS. Section 3 exposed that the carbon price is the cornerstone of the current climate change public policy and the carbon tax and the ETS the main economic instruments to achieve climate targets. The theoretical framework has discussed the advantages and disadvantages those economic instruments may carry on when implemented in a context of imperfect competition, heterogeneous abatement costs, and market concentration.

In section 5 I show that in the analyzed period 32,21% of the GHG emissions are related with the energy supply. In the same section, I compute a Herfindahl-Hirschman Index (HHI) to show that the manufacturing industry of energy, responsible for the energy supply in Colombia, is highly concentrated. Besides, the energy industry has heterogenous abatement costs, which implies the marginal cost of reducing GHG emissions is positive and increasing.

These results lead me back to the research line of Nordhaus, W. D. (2006) stating the relevance of the curvatures between the benefit and cost functions. Regarding efficiency, price-type regulation is preferable if the curvature of the cost function from reducing GHG emissions predominates over the curvature of the benefit function. Conversely, the quantity-type is preferred if predominated the curvature of the benefit function.

For Colombian context, I found the curvature of the cost function is highly non-linear and thus, the marginal cost of reducing GHG emissions is positive and increasing, which means is very sensitive to the level of emissions. Such a result is explained by the heterogeneity on the abatement costs of the energy industry, suggesting diversity on the options to reduce emissions. At the beginning of the MACC, the cost is negative, which implies the adjustments represents savings to the firms and are not only affordable but a possible source of rents. While the industry moves up toward a cleaner path, gets up on the curvature realizing that any additional improvement has a higher marginal cost.

On the other hand, as the climate change damage is the externality effect from the added GHG stock, the marginal benefits of emissions reduction is mostly invariant to the current level of emissions. The curvature structure is close to linear because the added GHG emissions stock is a linear result with respect to the current GHG emissions. Therefore, the marginal benefit is likely to be positive, although closer to become constant.

According to the above discussion, in the energy industry of Colombia, the curvature of the cost function predominates on the curvature of the benefit function. In concordance with the mentioned theoretical statement, price-type regulation is the best option for the industry. Therefore, Colombia did right by implementing the carbon tax. As stated earlier and is detailed extensively in Appendix B, Law 1819 in Article 221, 222, and 223 defines the National Carbon Tax regulation; its taxable base and tariff; and the specific destination of the tax. Since the tariff setting on fifteen thousand pesos ($ 15.000 COP) per ton of CO2eq, the values of the tariff per unit of fuel are the following:

Table 6.1: tariff per unit of fuel

Fosil fuel	**Unit**	**Tariff/ Unit**
Natural Gas	Cubic Meter	$29
Liquefied Petroleum Gases	Gallon	$95
Gasoline	Gallon	$135
Kerosene and Jet fuel	Gallon	$148
Gas/Diesel Oil	Gallon	$152
Fuel Oil	Gallon	$177

Source: Law 1819 of December 20 of 2016 - Colombia

Three important aspects must be highlighted from those articles. First, the carbon tax is implementing an upstream regulation. Second, coal has not been taxed. Third, the levied amount about $5USD per ton of CO_2eq is lower than the recommended minimum of $50USD per ton of CO_2eq (Nordhaus W. D.; 2014).

The carbon tax was implemented to address climate change, but as shown in the law, the tariff distanced from the recommended in the literature. Such distortion leads to rethinking that the curvature's structure is not enough to define the best instrument. The features of the context, as the market concentration, may affect the effectiveness of the instrument.

Since on the 27th of July 2018, Colombia also adopted a climate law, including the first legal step for the implementation of a cap and trade scheme, and defining a three years deadline for the national government to regulate all the provisions of this law. I will continue the analysis checking out the effects that market concentration and heterogeneity on the abatement costs may have on continuing implemented the carbon tax or the eventual implementation of an energy-only ETS. Over this specific scenario, I will discuss the opportunities firms may find to exercise their market power on each of the most relevant steps to reach the carbon price through the two instruments.

To keep the analysis within manageable limits I keep the pure strains of the two mechanisms, but it is important to bear in mind there is an increasing trend of mixed systems and stepwise implementation.

The Point of Regulation - Upstream vs. Downstream Regulation

The point of regulation is described as upstream or downstream according to where the levy is collected. Downstream regulation refers to when the levy is collected where emissions are generated and emitted into the atmosphere. On the other hand, upstream regulation refers to when the levy is collected at the point where a product, which in the future will release GHG emissions into the atmosphere (e.g. via combustion or burning), is produced or commercialized (e.g. refineries or importation point).

For the regulation of GHG emissions, upstream systems are highly recommended because from an administrative and institutional point of view can facilitate enforcement while ensuring wide coverage. Additionally, an upstream point of obligation has administrative benefits because there are fewer entities to regulate than at the downstream level (PMR; 2016).

At this decision point, there is not much space to exercise market power. But heterogeneity may make preferable the upstream because of simplicity for assessment of enforcement.

The Sectors to Cover

Since energy supply has a high responsibility on the GHG emissions of Colombia, the well-functioning of the energy market, plus the existence of strong regulation institutions for the energy production and import makes the energy sector likely to be the most effective upstream point of regulation. Regulation over the energy sector seems viable because allows for costs to be passed down to consumers. That generates incentives for mitigation wherever energy is used. Thus, the participants in an energy-only ETS would be pretty much the same as the participants in the carbon tax.

I propose to add the major producers of coal, to convey such charge to the coal consumers too. The absence of the coal on the carbon tax regulation may exemplify the market power excise from the Coal firms. Lobby action may have caused the exemption to sub-industry of coal. It also may cause the distortion on the tariff definition. A tariff lower than the recommended would lead to vanish the tax effect through it passed down to the consumer. If the consumers do not feel the change in the fuels price, will not change their fuels demand. Thus, the revenue from fuels sales will not be affected while the emissions target neither would be achieved.

Choosing the Entities to Regulate

Regarding the entities to regulate, the carbon tax has an immense administrative advantage over the ETS. The carbon tax law establishes that the DIAN[12] is in charge of the levy collection. The law also assigns the task of verifying compliance with this single entity, one that already exists and has experience on this type of task. Further, for the DIAN it is relatively easy to verify compliance of the regulation. The institution only requires matching the sales data from the regulated fuels with the already defined tariff to be paid for each fuel unit, according to the reference. In the mentioned scenario, firms have no opportunity to exercise market power, to collude, or to modify the tariff to paid. Since the tariffs have been defined time ahead, there are no effects from heterogeneity among cost neither incentives to improve technology.

A con of the carbon tax is that does not encourage technological change. The heterogeneity in the abatements cost implies there are many chances to reduce GHG emissions by the improvement of the productive processes. But since the carbon tax is a levy charged at fossil fuel sell for combustion, it does not bear any relation to an economically oriented strategy to encourage technological change. In the sector, such technological change would mean improvements on the production processes which represents benefits and saving for the firms while reducing fugitive emissions.

[12] DIAN is the Spanish acronym for National Tax and Customs Directorate of Colombia *"Dirección de Impuestos y Aduanas Nacionales de Colombia"*

The carbon tax has no more bargaining processes or gaps to change the rules. Which leads me to conclude that the only scenario where market concentration may have effects through exerting market power is on the legal negotiation of the terms for the law. As has happened with the current carbon tax such market power generated distortion on the tariff and the regulated fuels.

On the other hand, the implementation of an ETS requires the creation of several institutions, which may lead to diverse opportunities to exert market power. I focus on the points that may affect the effectiveness of the instrument.

As was mentioned in Section 2, allocation of allowances is crucial in designing emissions trading systems or cap and trade scheme. And according to van Dyke, B. (1990), two allowance mechanisms are hotly debated: allocation via auction or via grandfathering. On the scenario of Law 1931 of 2018 where policymakers decided to implement an auction to allocate the allowances among the regulated firms, I found three possible risks for the effectiveness of the instrument.

First, firms from the energy industry may collude to push down the equilibrium price from the auction. To deal with that Cramton, P., & Kerr, S. (2002) suggest a standard ascending-clock auction, like Treasury debt sales. Is important to bear in mind that Treasury debt sales also take place into a market of few firms with high market power. Therefore, market power control depends on the mechanism design applied to the auction, which should generate scarcity and competition from the first allocation moment to encourage the price equalization (Hepburn, C. et al.; 2006).

Second, as mentioned above, output HHI in the energy industry is high. The industry is highly concentrated, but sub-sectors in the industry are too. This situation may generate inefficiencies when the leader of each of the sub-sectors, as the biggest producer is also considered the highest emitter, and thus, the biggest claimant of allowances. If that firm exerts its market power to hoard or monopolizes the allowances may generate two main difficulties:

The first difficulty associated with such monopolization is that the leader firm may not want to go to the secondary market. Forcing the smaller firms to change their technologies in record time, or to assume the institutional punishment for the non-compliance behavior. According to Anouliès, L. (2017), the initial allocation of the emission allowances modifies the market structure, and firms' heterogeneity magnifies that effect. In this case, the continue scarcity on allowances may lead to a reduction of the GHG emission but for the wrong reason. The heterogeneity among firms may push the weakest firms or those with the highest abatement cost to exit the market. Reallocating the market power amongst the other firms.

The second difficulty is related to the loss of trust on the market as climate change policy. If the secondary market does not have an active behavior. In the face of scarcity of allowances to be transacted and lack of enforcement mechanism, regulated firms may ignore the regulation and any possible punishment. This is particularly dangerous given the high market power, the low substitutability for fossil fuels, and its importance for growth.

Third, the equilibrium price set on the auction can be higher than the abatement cost, which may discourage transactions on the secondary market in the first periods. Since the abatement cost curve have negative values, for firms is possible to reduce GHG emissions without affording extra charges. The fact of abatement costs lowers than the auction price for the allowances would lead to an excess of allowances supply with little demand in the secondary market would result in a fall in the allowances price. This situation may be good for the environment because encourage technology changes to reduce emissions rather than to pay the carbon price, but negative to the instruments because undermine its implementation.

If the policymakers decide to allocate the allowances via grandfathering, the number of allowances that each firm may receive could be decided according to historical emissions or the historical output of the firms.

Allowances allocated according to historical emissions would be equivalent to give subsidies to the firms. Even worst, it would reward the dirtiest firms and punish those who, independently and autonomously, have made technological changes to reduce their GHG emissions (Groenenberg and Blok, 2002). I can support such statement because according to Boemare, C., & Quirion, P.; (2002), the firms would receive a number of allowances equivalent to the number of emissions they need to back up. Therefore, those firms that emit more emissions would get more allowances than those that generates fewer emissions. The problem with this policy is that ignores the fact that the marginal cost curve of reducing GHG emissions in the energy industry is positive and increasing. Which means, that dirty firms afford a lower cost to reduce their emissions than firms with cleaner technologies. And thus, dirty firms not only having more opportunities to reduce their emissions at lower costs but also have more allowances for free, allowances that can be sell in the secondary market. All this discussion reduces to the fact that dirty firms have the incentive to reduce their GHG emissions, because is affordable, and go out to sell the remaining allowances in the secondary market, which becomes in an additional source of income. An award for dirty companies. Such a policy not only would be not popular in political terms but may send a very bad signal to the market, while increases lobby actions.

Finally, allowances allocated according to historical output. A drawback of output allocation is that firms can steer future endowments by a strategic behavior undermining the cost-effective structure of the cap and trade scheme (Böhringer, C., & Lange, A.; 2005; Anouliès, L.; 2017; Demailly, D., & Quirion, P.; 2008). In a context of high market concentration and very few firms producing goods with few substitutes, this policy option may lead to enforce the concentration trough barriers to entry in a regulated sector. The rent-seeking behavior in firms with market power may also lead some firms to strategically play with their output which can affect consumers welfare.

To conclude the analysis, the carbon tax has fewer institutional interactions and thus, offers fewer opportunities to exercise market power than the ETS. Therefore, if lobby action on the legal bargaining is controlled could be an effective instrument to address climate change in Colombia.

Despite, the carbon tax may face two political costs. First, increasing and repeated regulation on the same formalized sectors could be politically unpopular while the rest of the economy continue to be informal and emitting. Second, some sectors may argue that increasing the cost of fuels may affect the competitiveness of the country.

Additional to the previous discussion, Table 6.2 is showing some of the most relevant theoretical and empirical statement to promote the implementation of the carbon tax and the ETS. I complimented the analysis, checking for the viability for such statements regarding Colombian context.

As is shown in Table 6.2, the ETS and the carbon tax have roles to play on the different ways to achieve the optimal carbon price and thus, the country's target on emissions reduction. However, it is important to carefully understand how the economic instruments might interact, and how to deal with the problem of overlap in a mixed or stepwise implementation. Particularly, because in that case is likely to have problems on establishing a unique, clear and uniformed carbon price, which can lead to confusing signals and inefficiency.

Table 6.2: Instruments discussion for the Colombian context

Theoretical and Empirical Statements		Viability on the Colombian context
Carbon tax	**ETS**	
Have the advantage of being implementable by the government, in an individualized way, without international agreements, although is expected to be harmonized with international carbon taxes.	May require international cooperation and coordination to set the market design and transaction rules, for national and abroad allowances.	In Colombia, a tax implementation or adjustment requires Congress approvement (which the current carbon tax already has). The Congress process makes the tax subject of a negotiation process, political interests, and lobby actions. The ETS may be approved by a decree of the MADS. The concentration on the manufacturing industry of energy implies market power, which may lead to an ex-ante no compliance behavior (for a carbon tax) or the not enforcement for the ETS ex-post
Generates revenue for the government, and alternative uses of it are possible, including those related to climate change (mitigation and adaptation)	In the case of using auctions for allowances allocation, may generate revenues, which may have alternative uses, including those related to climate change (mitigation and adaptation)	In Colombia, a specific destination for taxes is not legal (even though the current carbon tax have it, article 223, Law 1819 of 2016) Specific destination of revenues would be possible with an ETS, that can encourage technological change, as the mitigation, and adaptation for climate change
Taxes on fossil fuels can success with emissions factors, which are fairly good approximations and thus, avoid direct emission measurement which represent an extra cost for firms	ETS participants would require direct measurement of GHGs which is not very usual in Colombia and can be relatively costly to medium and small firms	The direct measurement extra-cost could be an advantage for the carbon tax. On the other hand, the extra cost could be seen as an incentive for firms to review their processes an enroll in a tecnology change to avoid the frequent measurement process and even some regulations. Also, regulated firms are not small and have negative abatement cost, which means the process will represent benefits.
Provides certainty about the carbon price, and thus, on the government revenue, but not on emission reduction	Provides great certainty about quantities of emissions but not about the carbon price. The main goal of the ETS is to make emissions scarce, not costly. The price is only a means to an end, but price volatility is a risk and could become a serious issue over market trust	Price certainty and quantity certainty are both important. The firms would like clear and simple price signals for decision making. But on a context of high market power, rent-seeking and collusion are possible risks. Therefore, the market power the firms have in their industry can be transfer to the ETS.
Focuses on fuels, emissions generated by these and the sectors that use it.	Can cover a great part of the economy and its emissions, even those from the AFOLU group, by the inclusion over time of the firms that belong to it.	The carbon tax has low chances to cover emissions from the forestry sector, the greater emitter on Colombian case. Anyway, other complementarian instruments could be designed. The ETS could cover forestry sector by the inclusion of the reforestation projects as participants of the market on a role of allowances suppliers rather of demanders. Ilegal forestation is a problem to either instrument.
Implementation can be fast and effective, but inflexible	Offers flexibility for implementation, gradual adjustment of the participant sectors and allows complementarity policies. Allowances allocation may be used as an incentive, e.g grandfathering may lead the incumbent firms to success on emission reduction through the rent-seeking behavior, and move to auction over time could be a transparent policy.	The adjusts for changes of the carbon tax would require of a law process through the Congress and market power from the manufacturing industry of energy may play a relevant role there again. Even when ETS flexibility allows changes on rules without Congress processes, the market power may influence the allowance allocation to privilege rent-seeking behaviors
Does not generate particular incentives for governments compliance, does not encourage international participation either promote centralized global governance of the international regime of climate change	Provides incentive for poor countries to participate. To focus carbon policy on trading encourage interaction of developed and developing countries. Which open the door for cooperation among countries to achieve their targets, maintaining prices at levels that will give incentives for both, reduction at home and purchase abroad	The market power of the manufacturing industry of energy may distort the definition of the carbon tax tariff, without consequences. Whereby the international network of the ETS may have advantages for the abatement compliance of Colombia. The international watchfull of emission reduction may enforce to achieve the national target and the emissions capture through reforestation projects can be sell to other countries, which encourage reforestation and benefits the country's economy
Given that preferences change as a result of public discussion, and that involves a change in public understanding of responsible behavior. (Stern, N.; 2008). The carbon price may eventually become obsolette and an institutional process to turn it off coul be required.		The carbon tax may be easier to disassemble because does not require an institutional construction. While the institutional complexity of the ETS can make complicated to disassemble because of the number of required intitution for its operation. The mentioned argument applies to its initial assembly too and the cost that it implies. Given the few firms that make up the regulated sector, such cost could be excessive.

Source: author analyze based on literature review

7. Conclusions

The main conclusion from this study is that the carbon tax is the best instrument to address the carbon price on the climate change policy in the Colombian context. The reason is its simplicity, ease implementation, and few spaces to be affected by the market power of the sector.

I used the research line of Nordhaus, W. D. (2006), remarking the importance of the structure curvature from the damage function and the MACC. For the energy industry of Colombia, I found the curvature of the cost function predominates on the curvature of the benefit function. In concordance with the mentioned theoretical statement, price-type regulation is the best option for the industry. Therefore, Colombia did right by implementing the carbon tax to achieve the carbon price. Although the current tariff of the carbon tax of Colombia is about $5USD per ton of CO2eq which is lower than the recommended minimum of $50USD per ton of CO2eq (Nordhaus W. D.; 2014).

Regarding the current carbon tax, it implements an upstream regulation, but coal has not been taxed. One could speculate that it is the result of lobby actions. Therefore, I analyze how the features of the context, as the market concentration, may affect the effectiveness of the instruments. The carbon price through any of the instruments, either a carbon tax or an ETS, should be able to reflect the relative price of facing a cleaner technology, and the abatement marginal cost; which means, the marginal cost of reducing GHG emission by a technology change. Also, either with cap and trade or carbon tax, revenues should be used on promoting technology change

Regarding carbon tax implementation I found that, through lobbying, the market concentration may affect the reach of the right tariff to fit the target. Such distortion not only affects the effectiveness of the instrument in relation with the objective of reducing emissions. It also makes hard to match the domestic carbon tax with the global carbon tax. Therefore, lobbying may represent an ex-ante non-compliance behavior to the carbon tax objective. Regarding allowances allocation, I found the problem is not the mechanism used, but the probability to participate in the secondary market with any of those. The reduced number of firms in the sector and the lack of required transaction amongst them explain the low participation. Without an active secondary market, the cap and trade scheme lose its purpose which reduces to an ex-post lack of enforcement of the policy.

8. Policy Recommendations

- I recommend continuing with the carbon tax to address the carbon price but adding some changes. I propose to include the major producers of coal, as well as, increase the tariff. Further, to reduce the effects of the ex- ante lobbying, I suggest bearing in mind the importance of setting a tariff possible to be harmonized globally.

- To encourage technological change and improve production processes I recommend the design of complementarian policies for the energy industry, focusing on energy efficiency. Such policies would heft to deal with the disadvantage of the carbon tax to encourage fugitive GHG emissions reduction.

- Regarding the political cost of increasing regulation on the same formalized sectors, I recommend complementarian policies to cover GHG emissions stemming from the other sectors while formalizing is encouraged.

- The implementation of the ETS could be effective because it allows incorporating more IPCC groups, and thus, cover more GHG emissions. For that to be possible the Country needs to work on formalizing the economy on the three years available to regulate the ETS, increasing the number of firms and sectors that could be regulated through the instrument. And on the eventual implementation of an ETS, I suggest allocating the allowances through auctions as mentioned on Law 1931of 2018.

Appendix

A. Carbon Pricing Appendix

According to the World Bank Carbon Pricing Dashboard database, and its latest update on the 1st of November 2018, initiatives related with carbon pricing are now in more than sixty national or subnational jurisdictions with some implementing more than one instrument in complementary ways. The instruments to address the carbon price are classified in ETSs and carbon taxes according to the way of technically operating. But is important to bear in mind that the ETS does not only refer to cap-and-trade systems but also baseline-and-credit systems as the one implemented on British Columbia and baseline-and-offset systems at the national level as implemented in Australia (World Bank; 2018).

What is the difference between a carbon tax and an ETS?

As mentioned above, both a carbon tax and an ETS may help to internalize the market failure presented by the GHG emissions. The difference between an ETS and a carbon tax is that an ETS represents a quantity approach because limits the number of emissions permitted but allows the market to set the price for a ton of CO_2eq. In contrast, a carbon tax represents a price approach, and thus, works the opposite way: the tax sets the price of an emitted ton, and given this price, the market will respond with the corresponding reduction in the quantity of GHG emissions

In addition, the promoters of the ETS are used to say that it uses may often produce a variety of co-benefits, including the possibility to expand regulation to different sectors and the capacity to involve the private sector, green investment, and international cooperation. While the carbon tax is just extra taxation (ICAP; 2016; PMR; 2016)

Table A.1 shown the countries implementing a carbon tax and Table A.2 those chosen the ETS as the instrument to address carbon pricing at the national level. Tables also show the status of the instrument regarding implementation. Scheduled refers to "scheduled for implementation" meaning that was formally adopted through legislation and have an official planned start date. On the other hand, “under consideration” label refers to a scenario where official sources announced its intention to work towards the implementation of the instrument (World Bank; 2018).

Table A.1: Countries implementing a carbon tax at the national level

Country	Year of implementation	CO2eq Price USD	GHG emissions covered [MtCO2e]	Initiatives overlapping GHG emissions covered
Argentina	2019	N/A	79.25	N/A
Canada	2019	N/A	N/A	N/A
Chile	2017	5.00	46.67	N/A
Colombia	2017	4.92	41.62	N/A
Cote d'Ivoire	TBC	N/A	N/A	N/A
Denmark	1992	26.44	21.58693116	EU ETS
Estonia	2000	2.27	0.76	EU ETS
Finland	1990	70.63	25.08995822	EU ETS
France	2014	50.81	175.632171	N/A
Iceland	2010	28.87	1.594285714	EU ETS
Ireland	2010	22.78	30.792	EU ETS
Japan	2012	2.56	999.4272087	Tokyo CaT, Saitama ETS
Latvia	2004	5.12	2.055018436	EU ETS
Liechtenstein	2008	95.71	0.059925838	N/A
Mexico	2014	2.72	307.33	N/A
Netherlands	TBC	N/A	N/A	N/A
Norway	1991	59.86	39.56060547	EU ETS
Poland	1990	0.07	15.53693138	N/A
Portugal	2015	7.80	20.80167748	N/A
Singapore	2019	N/A	42.02459252	N/A
Slovenia	1996	19.70	4.958970808	N/A
South Africa	2019	N/A	360.492624	N/A
Spain	2014	22.78	9.016716566	N/A
Sweden	1991	126.83	26.14402793	EU ETS
Switzerland	2008	95.71	17.97501032	N/A
United Kingdom	2013	23.24	136.4484747	EU ETS
Ukraine	2011	0.01	287.01	N/A

Source: author analyze based on Carbon Pricing Dashboard – World Bank

Table A.2: Countries implementing an ETS at the national level

Country	Name of the initiative	Status	Year of implementation	GHG emissions covered [MtCO2e]	Initiatives overlapping GHG emissions covered
Australia	Australia ERF Safeguard Mechanism	Implemented	2016	380.843135	N/A
Canada	Canada federal OBPS	Scheduled	2019	N/A	N/A
Chile	Chile ETS	Under consideration	TBC	N/A	N/A
China	China national ETS	Scheduled	2020	3231.900474	Beijing pilot ETS, Chongqing pilot ETS, Fujian pilot ETS, Guangdong pilot ETS, Hubei pilot ETS, Shanghai pilot ETS, Shenzhen pilot ETS, Tianjin pilot ETS
Colombia	Colombia ETS	Under consideration	TBC	N/A	N/A
Japan	Japan ETS	Under consideration	TBC	N/A	N/A
Kazakhstan	Kazakhstan ETS	Implemented	2013	183.2511	N/A
Korea, Republic of	Korea ETS	Implemented	2015	452.9059931	N/A
Mexico	Mexico ETS	Under consideration	TBC	N/A	N/A
New Zealand	New Zealand ETS	Implemented	2008	39.8467998	N/A
Switzerland	Switzerland ETS	Implemented	2008	5.951891	N/A
Turkey	Turkey ETS	Under consideration	TBC	N/A	N/A
Ukraine	Ukraine ETS	Under consideration	TBC	N/A	N/A
Vietnam	Vietnam ETS	Under consideration	TBC	N/A	N/A

Source: author analyze based on Carbon Pricing Dashboard – World Bank

B. Data and Information Source Appendix

Given that the purpose of this study is to analyze the viability and practicability of implementing a carbon tax versus an Emission Trading System (ETS[13]) as possible economic instruments to achieve Colombian target on climate change, I use three data sets: INGEI[14], EAM[15], and the abatement cost for the Colombian energy sector. The data allows me to characterize the Colombian energy sector, which is necessary and relevant to the analysis because targeting this sector facilitates an upstream approach. Therefore, my analysis will focus on energy supply (the electrical generation in the interconnected national system-SIN[16]-, the electricity generation in non-interconnected areas-ZNI[17]-, oil, gas, and coal), which corresponds to sources of GHG emissions along different production processes and the domestic use of energy.

[13] Another name for a cap and trade scheme of GHG emissions.
[14] INGEI is the Spanish acronym for National Inventory of GHG *"Inventario Nacional de Gases Efecto Invernadero"*. An inventory of emissions and removals of Greenhouse Gases (GHGs) is a report, delimited in a period of time and space, of the amount of GHG emitted directly into the atmosphere as a result of human activities and removals by carbon sinks, such as forests, crops or grasslands (IDEAM & PNUD; 2016).

[15] EAM is the Spanish acronym for Annual Manufacturing Survey "*Encuesta Annual Manufacturera*"
[16] SIN is the Spanish acronym for *Sistema Interconectado Nacional*
[17] ZNI is the Spanish acronym for *Zonas No Interconectadas*

B.1 INGEI and GHG Generation in Colombia

To analyze the generation of GHG emissions in Colombia, I use the 2012 National Inventory of Greenhouse Gases (INGEI), which contains the updated historical data series from 1990 to 2012. This INGEI edition includes, for the first time, information at the departmental level with municipal approximations. The INGEI of 2012 was carried out with regards to the 2006 IPCC guidelines, which makes Colombia one of the pioneering Latin American countries in effectively implementing this methodology (IDEAM; 2016).

Decree 291 of 2004 of the Ministry of Environment and Sustainable Development of Colombia (MADS[18]), states that the Sub-directorate of Environmental Studies of the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM[19]) is in charge of the construction of the INGEI as well as the coordination and preparation of all national communications on the matter of climate change. The 2012-INGEI was published in 2016, in the framework of the first Biennial Update Report (IBA) and the Third National Communication of Climate Change (TCNCC) (IDEAM; 2015). It is important to point out that some of the national statistics required for GHG inventory estimation lags up to four years, which explains why the latest version was published in 2016 but contains data until 2012 (IDEAM & PNUD; 2016).

An improvement of this INGEI version is that the results are ordered in accordance with the four groups stipulated by the 2006-IPCC methodology, while emissions are also disaggregated by the eight sectors of the Colombian economy. This structure not only surfaces the interrelation between both forms of analysis, but makes the data understandable and useful for research, policymaking, and sectorial analysis not necessarily related to the IPCC methodology. The 2006-IPCC establishes a methodology for accounting GHG emissions and removals into four major groups according to their origin: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and other Land Uses (AFOLU), and Waste. In parallel, the economic sectors of Colombia used by the IDEAM to group GHG emissions and removal are Mining and Energy, Transportation, Commerce Manufacturing Industry, Residential, Agriculture and Livestock, Forestry, and Sanitation.

As stated earlier, I mostly focus on the data related with Colombia's energy supply. From the IPCC methodology, the first group is Energy, where emissions are classified into: 1A Fuel burning

[18] MADS is the Spanish acronym for *Ministerio de Ambiente y Desarrollo Sostenible*.
[19] IDEAM is the Spanish acronym for *Instituto de Hidrología, Meteorología y Estudios Ambientales*

activities, 1.B Fugitive emissions from the manufacture of fuel, and 1.C Transport and storage of carbon dioxide, which, in turn, are divided into subgroups, disaggregated into five deeper levels. Table B.1 shows that, in this group, CO2, CH4, and N20 (direct GHG) emissions are reported from the burning of fuels, and fugitive emissions generated in the processes of different sectors of the Colombian economy.

Table B.1: IPCC Energy group and the economic sectors of Colombia

IPCC Groups			**Economic sectors of Colombia**
1. Energy General Methodology: 2006 IPCC Guidelines for national greenhouse gas inventories, Volume 2 - Energy (chapters 1 to 4)	1. A Fuel burning activities Emissions generated by the burning of fossil fuels and biomass in any kind of machine designed to produce the heat or mechanical work required to carry out different activities or processes in different sectors. Each of those is contemplated among subgroups 1.A.1 through 1.A.4	1. A.1 Energy industries	Mining and energy
		1. A.2 Manufacturing and construction industries	Manufacturing Industry
		1. A.3 Transportation	Transportation
		1. A.4 Others sectors	Commerce
	1. B Fugitive emissions from the manufacture of fuel Emissions generated in the extraction, processing, production, storage, and distribution of the fuels. It includes the emissions spontaneously released into the environment and those generated by the burning torch. These emissions are divided into two main subgroups 1.B.1 and 1.B.2	1. B.1 Solid fuels	Residential
			Agriculture and Livestock
		1. B.2 Non-solid fuels; Oil and Natural gas	Forestry
	1.C Transport and storage of CO2 No evidence of this process in the country at the time		Sanitation

Source: Author elaboration based on 2012-INGEI- IDEAM

Is also important to bear in mind that the inventories are estimations and not values perfectly known, and that estimations correspond to direct emissions to avoid double accounting. The estimations are made based on the IPCC set of emissions factors, which means that Colombia INGEI implements Tier[20]1 and Tier 2. To find the unit of GHG mass emitted, those factors are computed with the magnitude of the activity that generates the GHG emission. The estimation is made for six GHGs: CO_2, CH_4, N_2O, HFC, SF_6, and PFC. These gases are reported in units of

[20] The IPCC has classified the methodological approaches in three different Tiers, according to the quantity of information required and the degree of analytical complexity. Progressing from Tier 1 to Tier 3 generally represents a reduction in the uncertainty of GHG estimates, though at a cost of an increase in the complexity of measurement processes and analyses. (IPCC, 2003, 2006)

mass, Mton, and expressed in the common unit, CO_2eq. To transform the GHG into the common unit, the initial GHG mass must be multiplied for its Global Warming Potential (GWP). Thus, in the database, the estimation results are presented as gross emissions, gross absorptions (negative values) and net emissions totals (gross emissions minus absorptions) all in Mton of CO_2eq.

$$Emission\ (Unit\ of\ GHG\ mass) = Activity\ Data * Emission\ factor$$

The Emission estimation is based on activity data, which is the information on the amount of the activity generating the emission, and an emission factor, which is a representative value that relates the amount of a gas emitted to the activity associated with the emission, usually expressed as the weight of the gas divided by a unit of weight, volume, distance, or duration of the emitting activity. The data usually comes from the official statistics of each country on their different economic sectors, and the factor usually stems from an average of aggregated research (EPA, 1994).

Therefore, two important details improved the estimations of the sector: the use of country's emissions factors for the CH4 emissions from coal fugitives mining and the CO2 emissions from Colombian fuels combustion (IDEAM; 2016).

B.2 Annual Manufacturing Survey (EAM) and Market Concentration in Colombia's Energy Sector

To analyze the market concentration of the energy sector of Colombia, I estimate a Herfindahl-Hirschman Index (HHI), which required the use of data from the EAM, a panel dataset built by the National Administrative Department of Statistics (DANE[21]). The survey contains confidential information on the firms that belong to the Colombian manufacturing industry, classified by their productive activity according to the International Standard Industrial Classification of all Economic Activities (ISIC). I focused on the period from 2000 to 2012, because it has a homogenous structure and can be matched with the 2012-INGEI. Given the change from ISIC 3 to ISIC 4 during the selected period, the use of correlatives was needed to filter the activities of interest related with energy supply, as is shown in Table B.2. I worked with 248 observations.

[21] DANE is the Spanish acronym for *Departamento Administrativo Nacional de Estadística*

Table B.2: Activities of the Colombian economy according to the ISIC

ISIC 3	Activities	ISIC 4	Section
1010	Coal extraction (Coal stone)	510	Section B Mines and Quarries Exploitation
1010	Lignite coal extraction	520	
1110	Crude oil extraction	610	
1110	Natural gas extraction	620	
2310	Manufacture of coke oven products	1910	Section C Manufacturing industries
2321	Manufacture of petroleum refining products	1921	
2323	Fuel mix activity	1922	
	Generation of electric power Gas production; distribution of gaseous fuels by pipes	3511	Section D Electricity, Gas, Steam and Air Conditioning Supply
		3520	

Source: Author elaboration based on ISIC guides from EAM-DANE

B.3 The Abatement Cost of Energy Supply of Colombia and the Heterogeneity of Productivity of the Suppliers' Firms

To analyze the heterogeneity among firms of the energy sector, I use the abatement cost curves of the energy supply, which constitute a proxy over the technology standards inside the industry. This data comes from the study "Sectoral Analytical Products to Support Decision-making on Mitigation Actions at a Sectoral Level," carried out in 2014 by the Study Group of Urban and Regional Sustainability from Universidad de Los Andes. The study corresponds to the second stage of the 2011 project "Study of Abatement Curves and Mitigation Potentials in the Economic Sectors of the Agricultural and Livestock; Transport; Waste; Mining and Energy." (UniAndes; 2014).

The study, focused on the estimation of marginal abatement cost curves (MACC), reported the marginal cost of reducing GHG generation. In this case, it highlights the relationship between the cost-effectiveness of different mitigation options and the total amount of CO_2eq reduced in the energy supply of Colombia during the period from 2010 to 2040. Therefore, I use the MACC to analyze the differences in the mitigation costs of the sector and the viability of competitive technological change in the productive activities of SIN, ZNI, oil, gas, and coal under a carbon tax or an ETS as climate change policy.

Such analysis required the construction of a GHG baseline and projections of emissions in order to analyze mitigation options under different scenarios within the national context. In accordance with IPCC guidelines, the projection scenarios covered the period 2010 to 2040, and the year 2010 was selected as the baseline. Two approaches were used: the first is an inertial scenario, which represents the emissions that each sector would have if the same management practices observed today continue during the analyzed period; the second is the reference scenario, which includes sectorial goals and policies in process of implementation or expected to be implemented in the course of the analysis period. The latter approach represents the most likely scenario according to sector experts.

Sectorial experts validated the mitigation options carrying out a cost-effectiveness analysis on the reference scenario. The trajectory of the GHG emissions was estimated under the application of the selected mitigation measures, this is how the sectoral curves of marginal abatement cost were constructed.

B.4 The National Carbon Tax Law - Law 1819

As stated earlier, Colombia currently has a carbon tax. Law 1819 passed on the 29th of December 2016, in Article 221 defines: "*The carbon tax is a levy that falls on the carbon content of all fossil fuels, including all petroleum derivatives and all types of fossil gas that are used for energy purposes, provided they are used for combustion. The event generating the carbon tax is the sale within the national territory, retirement, import for own consumption or import for the sale of fossil fuels and is caused in a single stage with respect to the generating event that occurs first. […] The taxpayer will be the one who acquires fossil fuels, from the producer or the importer; the producer when making withdrawals for own consumption; and the importer when making withdrawals for own consumption.*"

And Article 222 continue with the taxable base and tariff stating: "*The carbon tax will have a specific tariff according to the* CO_2 *emission factor […] The tariff will correspond to fifteen thousand pesos ($ 15.000 COP) per ton of CO2 and the value of the tariff per unit of fuel will be the following:*"

Table 6.1: tariff per unit of fuel

Fosil fuel	Unit	Tariff/ Unit
Natural Gas	Cubic Meter	$29
Liquefied Petroleum Gases	Gallon	$95
Gasoline	Gallon	$135
Kerosene and Jet fuel	Gallon	$148
Gas/Diesel Oil	Gallon	$152
Fuel Oil	Gallon	$177

Source: Law 1819 of December 20 of 2016 - Colombia

Finally, the Article 223 defines the specific destination of the tax is *“The collection of the national carbon tax will go to the Fund for Environmental Sustainability and Sustainable Rural Development in Areas Affected by the Conflict ("Fund for a Sustainable Colombia") that is dealt with in article 116 of Law 1769 of 2015” [...].*

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