Effectiveness of carbon taxes in conjunction with offsetting mechanisms: The Colombian experience

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Preface

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1 Introduction

1.1 Economic mechanisms for greenhouse gas emission reduction at a national scale

The IPCC reports confirmed the solid causal relationship between greenhouse gases produced by human activity and global warming. This correlation has led to a rise in the severity and occurrence of extreme climate events like droughts, floods, cyclones, hurricanes, and wildfires (IPCC, 2021). The IPCC reports influence the current international negotiations and decision-making processes leading to a low-carbon economy and have been the scientific basis for international agreements, such as the Paris Agreement, which sets the goal of limiting global warming well below 2, preferably to 1.5 degrees Celsius.

There is a prevailing consensus among economists and various policy experts that implementing an economy-wide carbon-pricing system will be crucial for achieving cost-effective reductions in CO_2 emissions; however, economists and policymakers disagree on the choice of carbon pricing policy between carbon taxes and cap-and-trade mechanisms (Stavins, 2019).

Nevertheless, in 2019 in the US, the carbon tax was recognised as "*the most cost-effective lever to reduce carbon emission at the scale and speed that is necessary*" (Climate Leadership Council, 2019). A carbon tax is a burden imposed on each tonne of CO_2 emitted by polluters, aiming to internalise the externalities caused by such emissions into the environment. According to Betancourt (2015), internalising the cost of the externality into the final product helps make production and consumption decisions more consistent with environmental concerns.

Although the carbon tax might be a cost-efficient mechanism, there is still an intense debate about how to implement it to make it effective enough to reduce CO_2 emissions in the required quantity and time. First, significant challenges are associated with improving the accuracy of estimating the social cost of carbon to better determine the price of the carbon tax (National Academies of Sciences, 2017). Some experts estimated that to achieve a net zero emission target by 2050, prices should be US$34 to US$64 per metric ton in 2025 and US$77 to US$124 in 2030 (Kaufman et al., 2020). Second, a carbon tax is politically challenging to implement because internalising an externality implies that the price paid for goods and services will be higher, so that, while oil consumption is shifted to cleaner technologies, the final consumer will see a reduction in their purchasing power (Heal & Schlenker, 2019). In France, for instance, a carbon tax was implemented in 2018 that led to a fuel price rise affecting the middle class, whose salaries were too high to receive a subsidy but too low to afford fuel costs. The event triggered violent riots that led to a political crisis in the country. Finally, evidence regarding the effectiveness of this policy is quite limited; the scant studies, predominantly focused on the European context, suggest a relatively modest impact on reducing emissions (Green, 2021).

Between 1990 and 2020, forty-six countries have implemented carbon pricing mechanisms, with eight adopting carbon tax systems, twenty-two opting for cap-and-trade mechanisms, and sixteen employing a combination of carbon taxes and cap-and-trade systems (Dolphin & Xiahou, 2022). The global momentum towards carbon pricing has catalysed the development of innovative hybrid approaches. For example, policymakers in some regions have introduced carbon taxes alongside offsetting mechanisms (World Bank Group, 2023a). Offsetting mechanisms allow polluters to claim emission reductions by purchasing carbon credits from sectors not covered by the tax, which reduce or avoid emissions. Carbon credits represent a unit of measurement used to quantify carbon dioxide emissions avoided, reduced, or removed from the atmosphere, often through activities such as reforestation or renewable energy projects.

The Colombian case offers an example of such hybrid systems with offsetting, where a carbon tax of USD 5 per tonne of CO_2-eq was introduced in 2016. This tax is payable by producers and importers of gasoline, kerosene, diesel, fuel oil, and natural gas used in industries. It is applied at three stages of the fossil fuel distribution process: during (1) purchase, (2) self-consumption by the fossil fuel producer, and (3) import of fossil fuel. The carbon tax mechanism covers around 28% of the country's greenhouse emissions (IDEAM et al., 2021). In 2017, the Colombian government created an offsetting mechanism that allowed companies to avoid paying the carbon tax by offsetting their emissions through the purchase of carbon credits in projects implemented within the Colombian national territory. In 2018, the National Greenhouse Gas Emission Reduction Registry (RENARE) was created to oversee national-level greenhouse gasses (GHG) mitigation initiatives with the goal of meeting eligibility criteria for payment through results or offset.

The Colombian climate change policy has been studied from different perspectives. Rodriguez et al.(2022b) describe how the Colombian climate policy influenced firms' behaviour, finding that the Colombian carbon tax and regulatory pressure incentivised companies to develop a higher-quality climate action strategy. Additionally, large companies have invested in new technologies or innovation projects to improve greenhouse gas emissions management (Rodríguez et al., 2022a).

Wang-Helmreich et al. (2019) investigate qualitatively the potential impacts of a domestic offset component in a carbon tax on the mitigation of national emissions in Colombia, Mexico, and South Africa. They found that incorporating an offset component into a carbon tax has the potential for positive spillover effects, leading to emissions reductions in non-targeted sectors. However, offsets may weaken the carbon tax price signal because offsetting may reduce investors' incentives to switch to cleaner options in the targeted sectors and instead shift efforts to reduce emissions in possibly low-quality carbon credits.

1.2 Knowledge gap

While existing research has yielded valuable insights into the implications of the Colombian hybrid mechanism, significant gaps persist. Firstly, existing studies on the impact of a carbon tax on reducing greenhouse gas (GHG) emissions predominantly focus on European contexts, leaving a substantial void in our understanding of its efficacy in other regions. Secondly, prior investigations in Colombia have been limited. They primarily examine the behaviours of selected firms, as evidenced by the work of Rodriguez, or provide qualitative assessments of GHG reduction, as exemplified by Wang-Helm. These studies do not offer a comprehensive analysis of the temporal dynamics of the country's emissions after the implementation of the carbon tax and its offsetting mechanism. Finally, the literature exploring the combined impact of carbon taxation and offsetting mechanisms remains scant, further exacerbating the knowledge gap in this crucial area.

This thesis endeavours to bridge these disparities by conducting a detailed casual analysis of Colombia's GHG emissions, providing insights into the effectiveness of Colombia's carbon tax policy, extending our understanding of carbon taxation and offsetting mechanisms, and offering evidence of carbon tax effectiveness beyond the European context.

1.3 Objective and Research Questions

This research aims to explore how the implementation of the carbon tax and the offsetting mechanism in Colombia have influenced greenhouse gas emissions within the country.

The overarching research question of this thesis is how the implementation of the carbon tax and the offsetting mechanism in Colombia has influenced the country's greenhouse gas emissions. Specifically, four questions will be asked:

1) How have Colombia's carbon tax and offsetting mechanism been designed and implemented?
2) To what extent has Colombia's carbon tax reduced greenhouse gas emissions in the sectors subject to the tax?
3) How has the possibility of offsetting emissions by buying carbon credits influenced the carbon crediting market in Colombia?
4) Is the Colombian carbon credit market likely to fulfil the conditions of environmental integrity?

2 Conceptual framework

This chapter outlines the key concepts, variables, and relationships explored in this research. It commences with a detailed description of fundamental concepts, including the carbon tax, carbon crediting markets, and environmental integrity. Subsequently, it delves into the anticipated relationships among the carbon tax, offsetting mechanism, and emission reductions.

2.1 Carbon tax

Climate change poses significant costs to society due to carbon emissions generated by economic activities. These costs, known as the social cost of carbon, represent the damages caused by climate change that are not accounted for in the prices of goods and services (OECD, 2021). One key policy instrument to reduce carbon emissions is the carbon tax. Although the idea of a carbon tax gained traction following the International Conference on Atmospheric Change in Toronto in 1988, its conceptual foundation can be traced back to Pigou's proposal in 1920. Pigou suggested imposing taxes on activities that generate environmental pollution, aligning the prices of goods and services to avoid or reduce their adverse impacts on society (Timilsina, 2022).

A carbon tax imposes a financial burden on each tonne of CO_2 emitted by polluters and can take various forms. For example, in Colombia, the tax is levied on fossil fuels in proportion to the CO_2 emissions released during combustion. This approach penalises fuels with higher carbon content, such as coal or petroleum coke, more than those with lower content, such as natural gas. In addition, alternative approaches to applying a carbon tax have been adopted, such as taxing a good or service according to the CO_2 emissions produced during its production (Timilsina, 2022).

2.1.1 Domestic offset component of a carbon tax

The domestic offset component of a carbon tax is a hybrid approach implemented in countries such as Colombia, Mexico, and South Africa. In this approach, taxpayers are allowed not to pay carbon tax if it is demonstrated that the carbon emissions caused by their economic activity are neutralised through offsetting (Wang-Helmreich & Kreibich, 2019). Section 4.3. provides a detailed description of how this mechanism was implemented in Colombia.

2.2 Carbon crediting market

According to the World Bank Group (2023), carbon crediting markets facilitate the trade of carbon credits. Carbon credits represent units generated through voluntary activities aimed at avoiding or removing CO_2 emissions. Each carbon credit corresponds to the avoidance or removal of 1 metric tonne of CO_2 equivalent (tCO_2-eq). Examples of activities that generate carbon removal include carbon sequestration through afforestation or reforestation, while activities aimed at avoidance may involve capturing methane from landfills.

The World Bank Group (2023) also outlines the dynamics of the supply and demand sides of carbon crediting markets. On the supply side, activities that generate avoidance or reduction of CO_2 emissions must be subject to verification through an accreditation mechanism. Following the verification process, carbon credits are *issued*. There are three types of crediting mechanisms:

- *International crediting mechanisms:* These mechanisms are established under international treaties, such as the Kyoto Protocol, and are known as Clean Development Mechanisms (CDM).
- *Domestic crediting mechanisms:* These mechanisms are established by governments at national, supranational, or regional levels. An example is the California Compliance Offset Program or Canada’s Greenhouse Gas Offset Credit System.

- *Independent crediting mechanisms:* These mechanisms are established and managed by private entities, typically independent non-governmental organisations. Examples include Verra and Gold Standard carbon crediting programs.

In the Colombian carbon crediting market, carbon credits are supplied by international and independent crediting mechanisms.

On the demand side, as defined by the World Bank Group (2023), carbon credits can be purchased for offsetting emissions to fulfil various purposes:

- *Voluntary demand*: Entities may purchase carbon credits to meet voluntary goals or make green claims.

- *International demand*: Governments may acquire carbon credits to fulfil emissions reduction commitments outlined in agreements such as the Paris Agreement, or airlines may purchase credits to meet the obligations laid down in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

- *Domestic compliance demand*: Companies may need to obtain carbon credits to meet obligations stipulated by domestic laws, such as the Colombian carbon tax.

Once carbon credits have been acquired, the issuing crediting mechanism must *cancel* them to prevent other buyers from acquiring the same carbon credits. Crediting mechanisms account for carbon credits through registries, which are typically developed by the crediting mechanism itself.

2.3 Environmental integrity of carbon markets

The rationale behind the role of offsetting for carbon credit buyers lies in the assumption that offsets are economically efficient. This efficiency stems from the belief that emission reductions achieved in activities that issue carbon credits are the most cost-effective, given the currently available technology (Probst et al., 2023). However, to ensure that offsetting achieves real emissions reductions, offset projects must align with a series of integrity criteria.

According to TSVCM (2021)[1], ensuring the environmental integrity of carbon markets relies on several key factors, including additionality, permanence, and leakage, as well as ensuring that projects are real, monitored, reported, and verified. For the purpose of this analysis, I focused on evaluating additionality and permanence characteristics, as these aspects have been primarily discussed in projects associated with land-use change and forestry, as well as large-scale renewable energy projects (Espejo et al., 2020), which are the types of projects that dominate the Colombian carbon crediting market.

In general, additionality refers to the degree to which a project's emissions reductions or removals exceed what would have occurred without the project's implementation (Probst et al., 2023). Carbon crediting programs use different methods to assess additionality, and various approaches can be found in the literature. To harmonise these approaches, the ICVCM (2024) [2] determined that, regardless of the methodology used, demonstrating

[1] Taskforce on Scaling Voluntary Carbon Markets

[2] Integrity Council for the Voluntary Carbon Market

additionality always requires that the avoidance or reduction of emissions exceed those required due to relevant legal requirements. In addition, three assessment approaches were defined:

- Investment analysis assesses whether the revenue from the sale of carbon credits is necessary to make the project economically attractive and viable.

- Barrier analysis identifies any barriers or challenges that may prevent the implementation of a project without revenue from carbon credits, such as regulatory obstacles, lack of access to finance, or technological limitations.

- Market penetration assesses prevailing market conditions and practices to determine whether the project represents a departure from business-as-usual scenarios. If the project activities go beyond what is typically done in the market, it strengthens the case for additionality.

Permanence, on the other hand, is a criterion that mainly concerns nature-based solutions[3]. It refers to whether emission reductions or removals from mitigation activities are permanent or, in case of risk of reversal, whether measures are in place to address these risks and compensate for reversals. (ICVCM, 2024). The most common measure to ensure permanence is established buffer pools – a share of credits that are not sold but used to cover non-permanence risks (Probst et al., 2023).

Finally, double counting arises when two or more offset participants claim GHG reductions from the same project, or when, due to fraudulent practices or errors, accurate registration fails (López-Vallejo, 2022). In the case of the Colombian offsetting mechanism, double counting might occur when multiple companies use a single carbon credit to reduce the carbon tax burden on one tonne of CO_2, or when a single company uses a single carbon credit to reduce the carbon tax burden on more than one tonne of CO_2. To ensure accurate accounting of carbon credits, crediting programs should maintain a public registry to track *issuances*, which indicate when removal or reduction of CO_2 emissions has been approved, and *cancellations*, which occur when buyers acquire the carbon credits representing such emissions reductions.

2.4 Definition of variables and their relationship

To explore the influence of the carbon tax and the offsetting mechanism on greenhouse gas emissions in Colombia, the following variables are defined:

- Independent variables: The carbon tax and the offsetting mechanism represent the primary policy mechanisms under investigation. The carbon tax, implemented by the Colombian government, aims to internalise external costs related to carbon emissions. Conversely, the offsetting mechanism allows entities to offset emissions by acquiring carbon credits from emission reduction projects.

- Dependent variable: The reduction in carbon emissions corresponds to the extent to which Colombia has mitigated its environmental impact over a specified period. This variable reflects the core objective of the research, which is to assess the efficacy of policy interventions.

3 Natural based solution projects include conservation and avoided conversion (e.g., grassland/rangeland management, avoided deforestation), agriculture soil carbon sequestration, forestry sequestration (improved forest management, afforestation/reforestation, agroforestry), and wetland and marine ecosystem restoration/management (including seagrasses, saltmarshes, mangroves, and peatlands).

- Intermediate variable: The behaviour of the Colombian carbon crediting market serves as an intermediate variable. Changes in the market's dynamics may influence domestic CO_2 emissions, as it impacts the supply and demand for carbon credits within the country.

The relationship between independent and dependent variables is pivotal in understanding the dynamics of carbon emission reduction in Colombia. Implementing the carbon tax is expected to directly reduce domestic carbon emissions in the energy sector by increasing the price of fossil fuel products and, therefore, reducing their demand (Andersson, 2019). Simultaneously, the implementation of the offsetting mechanism stimulates transactions within the carbon crediting market. An increase in demand for carbon credits, driven by the desire to mitigate tax burdens, incentivises the development of emission reduction projects in diverse economic sectors such as land-use change and forestry within the country. However, the magnitude of the impact of the offsetting mechanism will depend on the environmental integrity of the carbon crediting market: a lack of additionality or permanence can reduce the efficacy of the carbon policy (Wang-Helmreich & Kreibich, 2019).

Furthermore, even when the environmental integrity of the carbon credits' quality is ensured, the offsetting mechanism might reduce the impact of the carbon tax by decreasing the burden on fossil fuel consumption and, therefore, attenuating the price signal supposed to reduce the final demand for fossil fuel-based products. As a consequence, the effect of offsetting is ambiguous: on the one hand, it can reduce the price signal effect of fossil fuel-based products from the targeted sector; on the other hand, it can lead to emissions reductions in non-targeted sectors.

Unfortunately, because the offsetting was implemented at the same time as the carbon tax, evaluating the impact of the offsetting alone is challenging. To address this, I will analyse two separate perspectives related to offsetting: (1) the impact of offsetting on the domestic carbon credit market, and (2) the carbon credit market environmental integrity. While these questions alone cannot directly answer the final question of the effectiveness of the offsetting mechanism, answering them allows us to assess whether at least necessary (yet not sufficient) conditions for the offsetting mechanism to be effective were fulfilled.

3 Methodology

The Colombian carbon tax and its offsetting mechanism could produce effects due to (1) influencing consumption decisions through the price signal, (2) redirecting private investment to sectors allowed to emit carbon credit, and (3) the government's reinvestment of the tax surplus in climate mitigation and adaptation purposes. I have designed this methodology to evaluate the effects of the carbon tax on (1) and (2). On The other hand, (3) cannot be addressed within the scope of this thesis due to the lack of public information provided by the Colombian government.

This chapter describes the methodology I followed to evaluate the effects of the carbon tax and its offsetting mechanism within the scope described above.

3.1 Describing the Colombian carbon tax

To answer the *first research question*, I performed a historical, descriptive analysis of the carbon tax in Colombia and its corresponding offsetting mechanism. This analysis aimed to clarify how the carbon tax and offsetting mechanism were established and implemented over time. The analytical method consisted of the following steps:

1) Revision of legal documents: The Colombian carbon tax has been designed and implemented through a series of laws, resolutions, and decrees since 2014. I reviewed all the legal documents to describe the background of the policy, the target activities of the carbon tax, the carbon price, and the tax revenue allocation.

2) Consulting official information: Colombian government entities such as the Administrative Department of the Presidency of the Republic, the Ministry of Environment and Sustainable Development (MADS), and the Ministry of Finance and Public Credit, made public information associated with the statistics of the implementation of the carbon tax and its offsetting mechanism. This information covered the number of tonnes of CO_2 offset and tax revenue since the implementation of the policy.

3) To complement the analysis, I included other official documents used by government entities to create public awareness and education about the carbon tax, such as public interviews, press releases, public consultations, and legal analysis documents.

The results of the descriptive analysis are compiled in section 4.

3.2 Estimating the Colombian carbon tax impact on target emissions

I answered the *second research question* using the same approach applied by Andersson (2019) to assess the impact of the Swedish carbon tax on the country's emissions. In Andersson's research, an empirical estimation of CO_2 emission reductions was made using panel data and the *synthetic control* method proposed by Abadie & Greaseball (2003). Andersson created a counterfactual unit (*synthetic Sweden*) composed of a weighted combination of OECD countries that did not adopt carbon taxes or similar policies during the Swedish tax period and had similar emission trajectories before this period.

To create *synthetic Colombia*, I used countries in the Americas that had not implemented a carbon tax or cap-and-trade until 2022 and shared similar trajectories in CO_2-eq emissions per capita and GDP per capita between 2000 and 2016. Given that the Colombian carbon tax was enacted in 2017, the pre-treatment period spans from 2000 to 2016, while the post-treatment period extends from 2017 to 2022.

3.2.1 The synthetic control method

Synthetic analysis is widely employed in quantitative comparative case studies when a singular, suitable comparison unit is unavailable. In such cases, the case of interest is best represented by aggregate entities—a combination of comparison units referred to as the synthetic control. According to Abadie et al., (2015), the synthetic control is *"selected as the weighted average of all potential comparison units that best resembles the characteristics of the case of interest".* Its purpose is to simulate what might have happened to the case of interest without intervention. Consequently, all potential comparison units used to create the synthetic control, collectively called the donor pool, are expected to share similarities in the outcome, believed to be driven by the same structural process as in the case of interest. These structural processes are represented in the method as covariates, commonly referred to as key predictors.

Suppose we observe $J + 1$ countries in the Americas that have not implemented carbon tax during a specific analysis period. Among them, only Colombia (denoted as country $j = 1$) has introduced a carbon tax on all the fossil fuels combusted in the national territory. As a result, we have J remaining countries in the Americas forming the donor pool. Countries in the donor pool are observed during the same periods, $t = 1, \dots, T$. Additionally, there are several pre-intervention periods, T_0, and post-intervention periods, T_1, with $T = T_0 + T_1$. Subsequently, Colombia is subject to the carbon tax during the periods $T_0 + 1, \dots, T$ and as is to be expected, the tax has no effect during the pretreatment period $1, \dots, T_0$. The goal is to measure the effect of the carbon tax on the CO_2 emissions of fossil fuel combustion in Colombia during the post-treatment period.

Synthetic Colombia can be represented by a $(J \; x \; 1)$ vector of weights $W = (w_2, \dots, w_{J+1})'$, with $0 \leq w_j \leq 1$ for $j = 2, \dots, J$ and $w_2 + \cdots + w_{J+1} = 1$. Each choice of W produces a particular set of weights, defining a potential synthetic Colombia. The selection of W is done by minimising the mean square prediction error (MSPE) between Colombia and synthetic Colombia concerning CO_2 emissions of fossil fuel combustion and the key predictors influencing the trajectory of these emissions over the pre-treatment. To find the synthetic Colombia, I used the statistical package for R called *Synth*, designed by Abadie et al. (2011). The Synth R packages output contains the predictor's weights (V) and the donor countries' weights (W) that define contributions to synthetic Colombia.

Lastly, the difference between Colombia's CO_2 emissions trajectory and synthetic Colombia in the pre-treatment period (2017-2022) reflects the impact of the carbon tax implementation on emissions from fossil fuel combustion in Colombia.

3.2.2 Sources of data

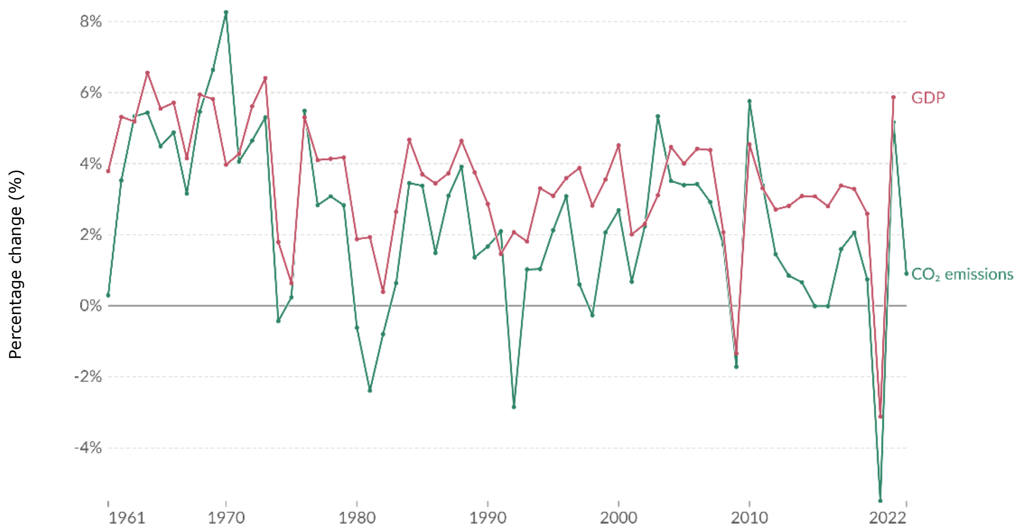
For this analysis, I utilised the PRIMAP-hist national historical emissions time series V2.5 (Gutschow & Pflüger, 2023), which provides national greenhouse gas emission pathways for every country. From the database I chose the IPCC sources described in Table 1, which includes all fuel combustion activities for the greenhouse gases CO_2, CH_4, and N_2O. In preparing the dataset, I converted territorial carbon emissions into territorial CO_2-eq emissions and normalised them by the respective country's population, resulting in annual panel data on per capita CO_2-eq emissions by country.

Table 1. Sources of emissions used in the synthetic analysis.

1.A. Fuel consumption activities	
1.A.1. Energy Industries	1.A.4. Other Sectors
1.A.2. Manufacturing Industries and Construction	1.A.5. Other
1.A.3. Transport	

As a key predictor, I utilised the Gross Domestic Product (GDP) per capita dataset provided by Goalminder (2022), which was derived from the World Bank and the Maddison Project statistics. While it would be ideal to incorporate a large set of key predictors in the synthetic control analysis, data availability for potential drivers of CO_2 emissions, such as energy use, urbanisation, or industrialisation, is limited or incomplete for countries in the Americas. However, GDP proves to be a robust driver for CO_2 emissions. Figure 1 illustrates the similarity between the pathways of the world annual change in GDP per capita and the world annual change in CO_2 emissions. Dong et al. (2020) estimated that economic growth alone is responsible for almost three-quarters (72.5%) of the growth of global emissions from 1997 to 2015. Additionally, a correlation analysis in my annual panel data indicates a strong positive relationship of 0.85 between GDP per capita and CO_2 emissions per capita. Moreover, a simple regression model provides confirmation of the significance of GDP per capita, with a p-value $< 2.2e^{-16}$ indicating statistical significance and an R^2 of 0.72, demonstrating that GDP per capita explains a substantial portion of the variability in CO_2 emissions. Finally, to the list of predictors, I add three lagged years of CO_2 emissions in 2000, 2008, and 2016 to better fit the pretreatment path, similar to Andersson (2019).

Figure 1. Percentage change in gross domestic product (GDP) and carbon dioxide (CO_2) emissions



Note: The figure displays the annual percentage change in global gross domestic product (GDP) and global carbon dioxide (CO_2) emissions. The figure is sourced from Our World in Data (2023)*.*

3.2.3 Selection of the donor pool

Abadie et al. (2015) outlined several requirements for constructing a donor pool. First, units affected by identical or similar events of interest should be excluded. Second, units that experienced substantial idiosyncratic shocks to the outcome of interest should be omitted unless the shock would have affected the treated unit in the absence of treatment. Lastly, it is crucial to limit the donor pool to a small number of units with characteristics similar to the treated unit; this helps avoid interpolation bias and overfitting.

Using these criteria, I initially identified all American countries that had not implemented carbon tax or cap-and-trade until 2022[4]. To ensure similarity between Colombia and Synthetic Colombia during the pre-

[4] A limitation of this approach is that, although all carbon pricing policies are taken into account, the effect of other climate policies implemented in the donor pool countries could be ignored.

treatment period, I manually excluded countries with significantly divergent trajectories of CO_2-eq emissions and GDP per capita and ran the synthetic analysis several times until I found the smallest MSPE for the pre-treatment period. This process yielded a donor pool of 14 countries in the Americas.

3.2.4 Placebo tests

To test the validity of the synthetic control results, I performed placebo tests. These are determined by iteratively applying the synthetic control method, randomly reassigning the intervention 'in-place' and 'in-time' to generate a set of placebo effects. Consistent observation of significant effects in the placebo test suggests that the estimated intervention effect in the unit of interest might be due to chance.

'In-place' placebo test: p-value

Given that there is only one treated unit, statistical inference and obtaining a p-value for the causal effect are complicated. Abadie et al. (2015) suggest using the 'in-place' placebo test to obtain the p-values, comparing how many in-place placebo tests get a MSPE ratio above the MSPE ratio of the treated unit.

I conducted the 'in-space' placebo test by iteratively assigning the treatment to each country in the donor pool. Subsequently, I calculated and compared the ratio between the post-treatment MSPE and the pre-treatment MSPE for Colombia and for each "placebo" treated country. A larger MSPE ratio of Colombia compared to the MSPE ratios of other countries in the donor pool suggests a true causal effect resulting from the treatment.

'In-time' placebo test

I conducted an 'in-time' placebo test by simulating the application of a carbon tax in 2005, and 2010, using the same technique employed for computing the synthetic control. I analysed the results by visually inspecting the potential effects of the placebo carbon tax on the CO_2-eq emissions paths for both synthetic Colombia and Colombia. If the placebo treatment produces a divergence in the trajectory of emissions between Colombia and synthetic Colombia in a post-treatment scenario, it might invalidate the synthetic control results.

3.2.5 Robustness

To assess the robustness of the results in a synthetic control analysis, Abadie et al. (2015) recommend the application of the leave-one-out test. This test involves iteratively resituating the donor pool to construct a synthetic unit, omitting one country that received weight in the original synthetic unit in each iteration. This sensitivity test allows an evaluation of the extent to which any particular unit influences the results in the donor pool.

The results of the synthetic control are compiled in section 5.

3.3 Assessing the impact of the offsetting mechanism on the carbon crediting market

To address the third research question, I conducted an empirical analysis using publicly available data from several carbon credit programmes on their registry platforms. I systematically tracked all carbon credits issued and cancelled in Colombia throughout its history. The registries which have issued credits in Colombia, consulted in February 2024, include:

I. Verra Registry
II. Gold Standard
III. Cercarbono
IV. Biocarbono

V. Clean Development Mechanism (CDM)
VI. Colcx
VII. GHG Clean Projects

While other platforms were consulted, no reported credits were issued/cancelled in Colombia. I systematically processed all the databases obtained from the registries, organising the data into two panel databases for all Colombian issuances and cancellations of carbon credits. These databases include details such as the carbon crediting program, project ID, project name, project type, serial number, quantity of credits issued or cancelled, and date of issuance or cancellation. To ensure consistency with the synthetic analysis results, I classified the carbon credit issuing projects according to the IPCC (1997) emissions sources/sink categories as described in Table 2.

Table 2. Carbon credit project classification according to IPCC source/sink categories

Project type	**IPCC source/sink category**	**Project classification by source/sink**
Energy industries (renewable / non-renewable sources)	1. Energy 1.A.1.a. Public electricity and heat production	1A. Energy - Hydropower 1A. Energy - Solar power 1A. Energy - Wind power 1A. Energy – Heat power
	1.A.1.b. Petroleum refining	1A. Energy - Petroleum refining
Chemical industries and manufacturing industries	If the reduction comes from changes in the combustion of fossil fuels in industry. 1. Energy 1.A.2 Manufacturing industries and construction	1A. Energy - Industrial processes
	If the reduction does *not* come from changes in the combustion of fossil fuels in industries 2. Industrial processes	2. Industrial processes
Transport	1. Energy 1.A.3 Transport	1A. Energy - Transport
Fugitive emissions from fuels (solids, oil and gas)	1. Energy 1.B. Fugitive emissions from fuels	1B. Fugitive emissions from fuels
Afforestation and reforestation	5. Land-use change and forestry	5. Land-use change and forestry
	For REDD+ projects	5. Land-use change and forestry – REDD+
Waste handling and disposal	6. Waste	6. Waste

Moreover, as detailed information on carbon tax offsets was unavailable in the Colombian government's public registries, I reached out to the Ministry of Environment and Sustainable Development (MADS) to access the official offset database. The MADS provided me with a comprehensive dataset containing information such as the offset year, economic activity of the applicant, type and amount of fossil fuel offset, project name, project type, quantity of credits cancelled, and carbon crediting program. Subsequently, I cross-referenced this database with the databases containing credits issued and cancelled to ensure full alignment.

Finally, I described the supply and demand of the carbon crediting market and its temporal behaviour concerning the implementation of the carbon tax and the offsetting mechanism. From the supply side of the Colombian carbon crediting market, I identified sectors where removals or reductions of CO_2 emissions took place, as well as the crediting mechanisms that issued the corresponding carbon credits. On the demand side, I identified the economic activities that applied the offsetting mechanism and the preferences for types of carbon credits. The outcome of this chapter is a comprehensive description of the changes observed in the carbon crediting market after the implementation of the carbon tax and the offsetting mechanism and its results are compilated in section 6.

3.4 Assessing the Colombian carbon credit market environmental integrity.

Initially, I ambitioned to directly evaluate the impact of the offsetting mechanisms on domestic emissions in Colombia by conducting a second synthetic analysis using the same methodology and data sources described in section 3.2. To address the identification problem due to the fact that the offsetting occurred at the same time as the carbon tax, I intended to analyse emissions from sectors not subject to the carbon tax but that issued carbon credits. Finding changes in such sectors would be a sign that the offsetting mechanism had positive spillovers. However, in identifying the sectors emitting carbon credits in Colombia, it became clear that this approach was unfeasible. The primary reason for this was the significant proportion of carbon credits originating from the '5. Land-use change and forestry' sector. Unfortunately, emissions data for this sector are scarce, and when available, they exhibit high fluctuations (Gütschow & Pflüger, 2023), making a within- and cross-sector comparison unfeasible.

Due to the data limitations, I shifted to a descriptive analysis, where I examined whether the environmental integrity conditions of carbon credits—specifically additionality, permanence and avoiding double-counting — are likely to be met. This analysis aimed to establish a qualitative assessment of whether the offsetting mechanism was likely, or not, to have induced a reduction in domestic emissions. To achieve this, I compared the carbon credits cancellations database obtained in section 3.3 with the offset database provided by the MADS (2024). Subsequently, I conducted an analysis for sectors '1. Energy' and '5. Land-use change and forestry', which collectively account for 93.1% of the total supply side of the Colombian carbon crediting market. My analysis primarily focused on evaluating additionality, permanence, and double counting, assessing their potential contribution to real emission reduction.

The results of the synthetic control are compiled in section 7.

4 The Colombian Carbon tax policy

This chapter provides a detailed analysis of the Colombian Carbon tax policy. The discussion begins with an overview of the background leading to the creation of the carbon tax, followed by a description of how it operates along with the offset mechanism. Finally, attention is given to the allocation of tax revenues. The carbon tax is closely tied to the overall national climate change strategy. This chapter focuses on key aspects of the strategy that directly relate to the carbon tax, omitting other elements that, while essential for the national climate change strategy, are not essential to the objectives of this thesis.

4.1 Background for the Carbon Tax Creation

In 1994, the Colombian government approved Law 164, ratifying the United Nations Framework Convention on Climate Change. Subsequently, in 2000, Colombia ratified the Kyoto Protocol through Law 629. As a developing nation, Colombia qualified for financial and technological support to fund its climate-related initiatives. Therefore, from 1994 to 2010, the government directed the climate policy towards estimating the country's greenhouse gas emissions, evaluating climate vulnerability and adaptation, and implementing the Clean Devel (Guardela, 2020).

Nevertheless, Colombia's National Development Plan[5] 2010-2014 introduced a more active policy approach by adopting the Low-Carbon Development Strategy concept. In this plan, the Colombian government recognised the necessity to encourage low-carbon economic growth to protect the competitiveness of Colombian sectors in a global economy influenced by carbon-intensive standards (Gobierno de Colombia, 2014). As described in the National Development Plan, within this period, the Colombian climate policy focused on identifying and asses the international commercial constraints associated with products and services with a high carbon footprint and the business opportunities generated by enforcing a low-carbon development. Although the National Development Plan had not yet incorporated the carbon tax, it did promote the concept of low-carbon development in Colombia and dictated the creation of the National Climate Change Policy, which integrated the carbon tax into the nation's climate change strategy.

In 2013, Colombia initiated its accession process to become a member of the Organisation for Economic Co-operation and Development (OECD). As part of this process, Colombia voluntarily requested an Environmental Performance Assessment from the OECD, which was carried out in 2014. The report pointed out that between 2000 and 2011, Colombian GHG emissions rose 13%, primarily driven by the growing transport and oil and gas sector activities. According to the report, transport was already the largest source of Colombia's CO_2 emissions from fuel consumption. The OECD also determined that the transportation fuel prices in Colombia did not adequately reflect their environmental impact, and in fact, these prices remained low due to subsidies and tax exemptions. As a result, the OECD recommended "*restructuring fuel and vehicle taxes to take account of their contribution to GHG emissions and local air pollutants.*" (OECD, 2014).

Another motivation for implementing the carbon tax in Colombia was the signing of the Paris Agreement. In 2015, Colombia submitted its Intended Nationally Determined Contributions (INDC) to achieve the Paris Agreement objectives. By 2030, the country aimed to cut its emissions by 20% compared to its projected emissions. Moreover, Colombia also aimed for an additional 10% reduction with sufficient international

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[5] In Colombia, a National Development Plan provides the framework and the strategic directives for the public policies shaped by the President of the Republic through his government team (Departamento Nacional de Planeación, 2023)

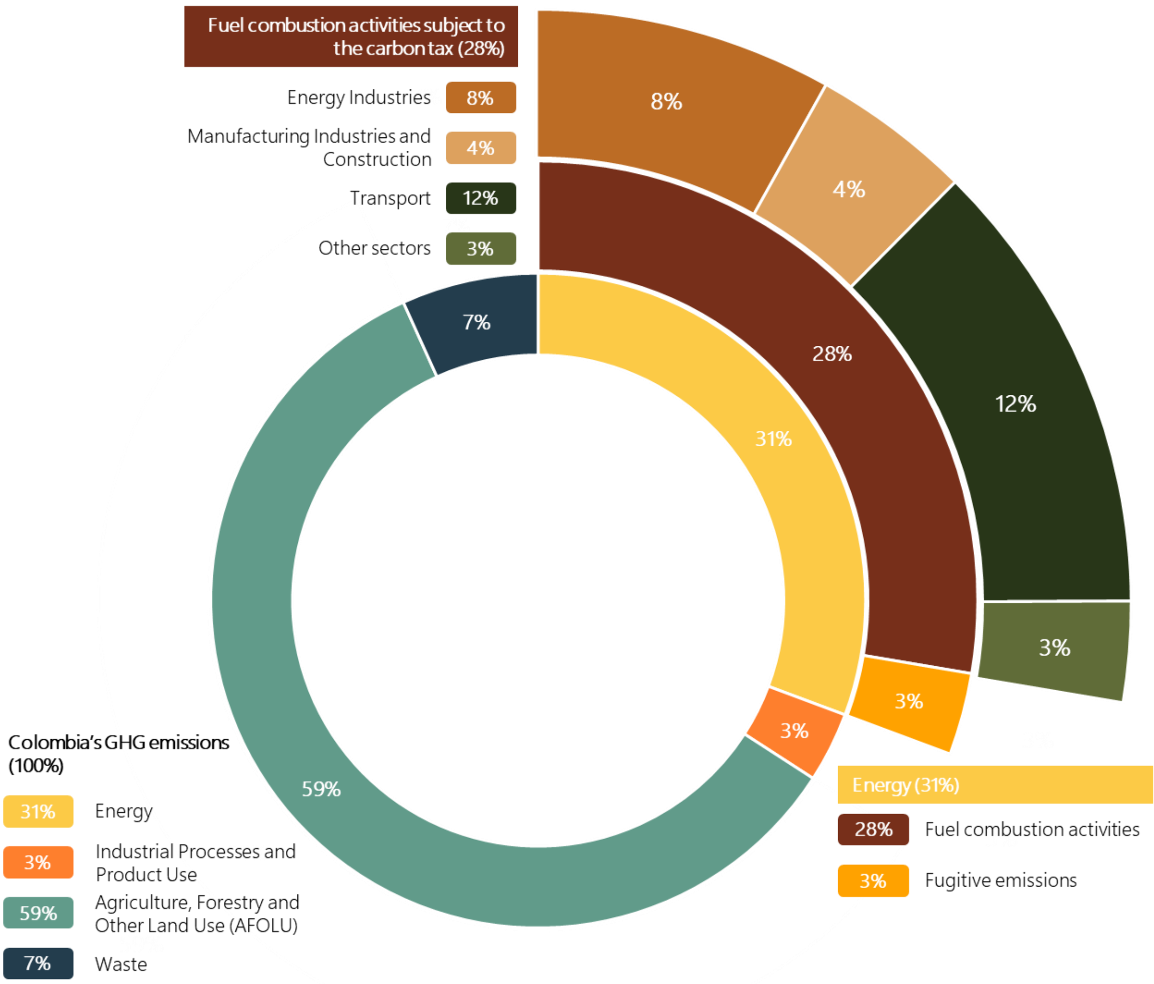
assistance. To attain the objective, Colombia expressed its intent to utilise economic and market-based instruments as part of its strategy (Ministerio de Ambiente y Desarrollo Sostenible (MADS), 2015).

Consequently, in 2016, the Colombian government enacted Law 1819, which presented a structural tax reform encompassing several levies, including the National Carbon Tax. One year later, in 2017, Colombia's National Climate Change Policy was published. The main objective of this policy is to integrate climate change management into public and private decision-making processes to move towards a low-carbon and climate-resilient development pathway, as initially outlined in the National Development Plan 2010-2014. Specifically, the National Climate Change Policy integrated the National Carbon Tax into one of its five strategic pillars focused on developing low-carbon and climate-resilient infrastructure, mainly within the transport sector (Ministerio de Ambiente y Desarrollo Sostenible (MADS), 2017).

4.2 How does the Colombian Carbon Tax work?

In 2016, the Colombian government enacted Law 1819, a structural tax reform designed to introduce new levies and enhance mechanisms to combat tax evasion. In line with the OECD recommendation and the Colombian INDC, the carbon tax was incorporated into this law and became the first Colombian environmentally focused tax.

Figure 2. Colombia's emissions covered by the carbon tax



Note: The figure shows Colombia's GHG emissions and details the "fuel consumption activities" burdened by the carbon tax. To elaborate on the figure, I obtained the data from the Third Biennial Update Report of Colombia to the United Nations Framework Convention on Climate Change (IDEAM et al., 2021).

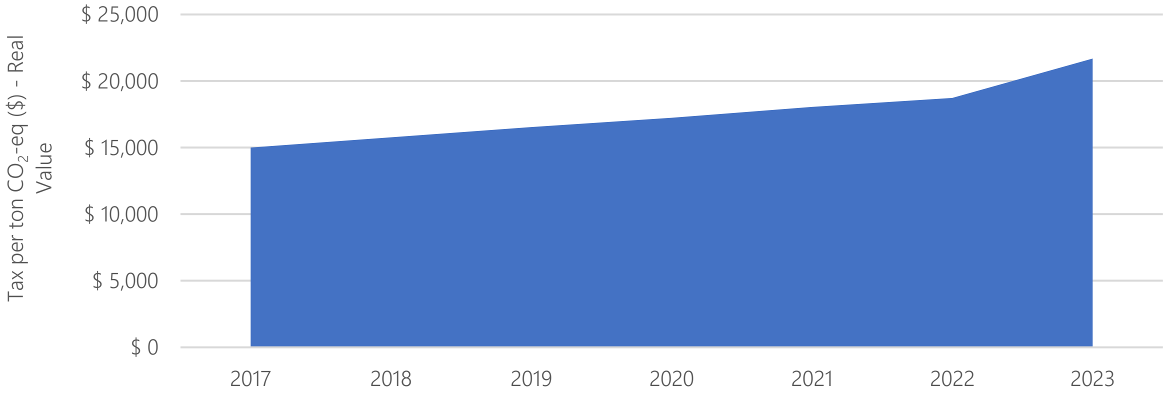
The tax is defined as a levy on the carbon equivalent content (CO_2-eq[6]) of all fossil fuels consumed within national territory. This tax is charged in one of the events that occur first: (1) purchase, (2) self-consumption by the fossil fuel producer, and (3) import of fossil fuel (Reforma Tributaria Estructural, Ley 1819 [Structural Tax Reform, Law 1819], 2016).

According to the last Colombian GHG emission inventory (IDEAM et al., 2021), fuel consumption activities produced around 28% of the country's GHG emissions. Consequently, the carbon tax concerns in more than ¼ of the country's emissions, represented mainly by the transport, energy production, and manufacturing and construction industries, which use fossil fuels in their production processes (Figure 2).

According to Law 1819 (2016), producers and importers of gas and petroleum derivates are responsible for withholding the tax. On the other hand, the taxpayer encompasses fuel wholesale distributors, producers, importers (when self-consumption occurs), and, in specific scenarios, large consumers who purchase directly from the fossil fuel producer or importer. In contrast, the final coal consumer is responsible for self-withholding and paying the tax.

The carbon tax came into force on February 1 2017, at a rate of 15,000 Colombian pesos per tonne of CO_2-eq (approximately €5[7]). Moreover, the carbon tax rate undergoes an annual increment of 1% plus the national Consumer Price Index (CPI). Figure 3 shows the historical Colombian carbon tax rate per tonne of CO_2-eq, which has maintained a relatively constant increase from 2017 to 2022. However, in 2022, Law 2277, which consisted of a tributary reform, increased the rate from 18,829 Colombian pesos to 20,500, accelerating the yearly increase.

Figure 3. Historical tax per tonne of CO_2-eq in Colombian pesos ($)



Note. This graphic shows the evolution of the Colombian national carbon tax rate for 1 tonne of CO_2-eq in terms of real value from its implementation in 2017 to the present. I obtained the historical carbon tax rate by consulting the annual carbon tax rate adjustment resolutions issued by the Colombian National Tax and Customs Administration (DIAN). I adjusted the figures by considering the CPI taken as the base year 2017. The CPI was consulted in the technical report of the CPI issued by the National Administrative Department of Statistics (DANE) (2023)*.*

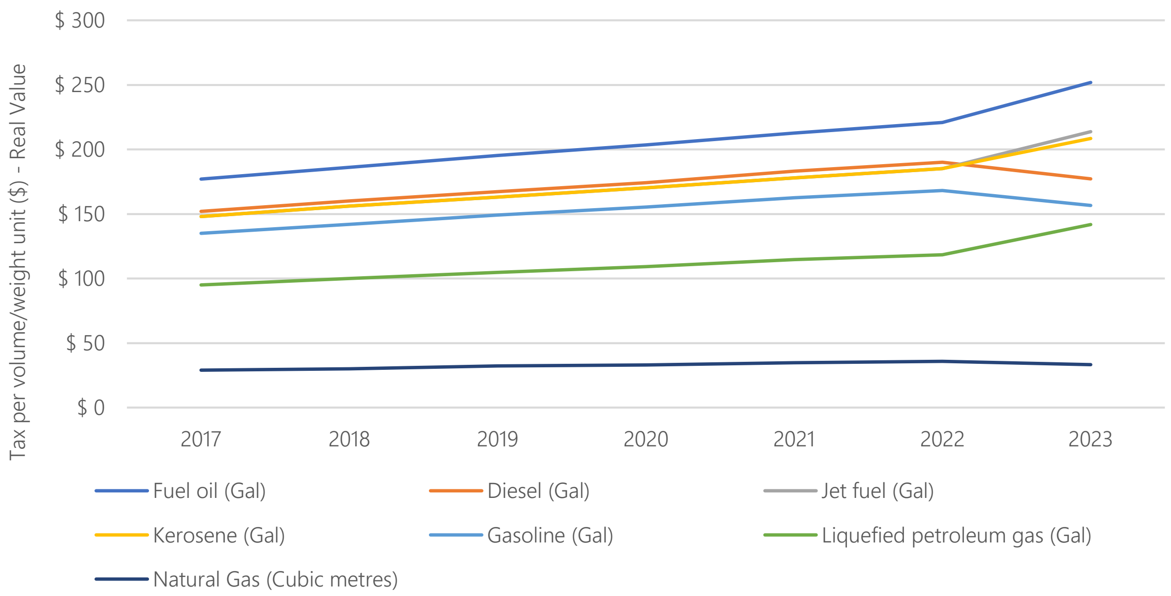
[6] CO_2-eq refers to "*the amount of carbon dioxide (CO_2) emission that would cause the same… …temperature change, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs*" (Intergovernmental Panel on Climate Change, 2022, pp. 541-562).

[7] This value is calculated by applying the average exchange rate in 2016 of $3,000.71 per euro.

As the carbon tax is levied per tonne of CO_2-eq, the amount of the tax varies for each type of fossil fuel, reflecting the different GHG content associated with each fuel. Consequently, the tax changes by fuel type and is determined by its GHG emission factor, expressed in kilograms of CO_2-eq per unit of energy (Reforma Tributaria Estructural, Ley 1819 [Structural Tax Reform, Law 1819], 2016).To simplify fuel trade transactions within the country, the carbon tax is set in terms of tonnes of CO_2-eq and volume or weight units for each fuel type.

Figure 4 shows the historical evolution of the Colombian national carbon tax rate for different types of fossil fuels; as expected, fossil fuels with a higher GHG emission factor will receive a higher tax rate. The annual variation in the tax rate per each fossil can also be affected by the annual update of the GHG emission factor, which the MADS determines according to changes in the composition of national fossil fuels and the IPCC recommendations (Decreto 926 de 2017 [Decree 926], 2017). This is evident in the case of diesel, gasoline, natural gas, and jet fuel, which have experienced decreasing carbon tax rates.

Figure 4. Historical tax per fossil fuel type in Colombian pesos ($)



Note. The graphic shows the evolution of the Colombian national carbon tax rate on different types of fossil fuels, calculated per unit of volume or weight, from its initial implementation in 2017 to the date. I obtained the historical carbon tax rate by consulting the annual carbon tax rate adjustment resolutions issued by DIAN. I adjusted the figures using the annual CPI to obtain the Real Value. I obtained the annual CPI by consulting the technical report issued by DANE (2023)*.*

In addition, according to Law 1819 (2016), coal usage will be subject to taxation starting in 2023. However, Law 2277 (2022) delayed the coal tax for a second time and introduced a phased approach, with a tax rate of 25% per tonne of CO_2-eq starting in 2025, escalating to 50% in 2026, 75% in 2027, and reaching 100% in 2028.

Finally, the law introduced certain exemptions for liquefied petroleum gas and natural gas, where the carbon tax is limited to specific industrial applications. Export and trading of fossil fuels in border areas were also excluded from applying the tax to disincentivise smuggling (Reforma Tributaria Estructural, Ley 1819 [Structural Tax Reform, Law 1819], 2016).

4.3 The offsetting mechanism (non-causation mechanism)

The Colombian Carbon tax was designed in conjunction with an offsetting mechanism, called in Colombian law as "non-causation mechanism". To offset, the taxpayer claims emission reductions by purchasing carbon credits from GHG reduction and removal initiatives in economic sectors not covered by the tax. As per Law 1819 (2016), taxpayers who offset their emissions and certify themselves as carbon neutral are exempt from the tax. According to the Ministry of Environment and Sustainable Development of Colombia (2023), the offsetting mechanism encourages the demand for Carbon Credits within the country and *"allows private resources to be directed to incentivise initiatives that generate socially and environmentally integral results"*. From 2017 to 2022, the Colombian government accepted offsetting 100% of the taxpayer's emissions. However, from 2023 onwards, only 50% of the emissions can be offset, meaning that the taxpayer can reduce only 50% of the burden by offsetting. This decision aims to increase the carbon tax signals (Reforma Tributaria, Ley 2277 [Tax Reform, Law 2277], 2022).

To regulate the offsetting mechanism, the MADS (2017) established a framework in Decree 926, which included procedures for accessing the non-taxation, guidelines for verification bodies responsible for certifying carbon credits, and criteria for accepting such carbon credits for tax exemption. In broad terms, the decree outlined the following:

- To be exempted, the taxpayer must offset their emissions before the tax is levied, which also implies that the offsetting of emissions must be done before the GHG emissions from fossil fuel use occur.
- GHG initiatives that produce carbon credits are considered valid for the offsetting mechanism if verified by an accredited third party (verification bodies) and maintain a publicly accessible record detailing the number of carbon credits verified and their ownership.
- Carbon credits should be generated within the Colombian national territory. Although on a transitional basis, until 31 December 2017, foreign carbon credits were accepted for non-taxation.
- These carbon credits cannot be derived from activities mandated by environmental authorities to compensate for the environmental impact of specific projects or activities subject to environmental authorisation.
- The initiatives certified as Clean Mechanism Development (CMD) were accepted for non-causation until 31 December 2018.

In 2018, Colombia enacted Resolution 1447 to regulate the System for Monitoring, Reporting, and Verification of Climate Change Mitigation Actions within the national territory. The resolution created the National GHG Emission Reduction Registry (RENARE), among other tools, to fulfil the objective. The resolution established that all the GHG reduction and removal initiatives in Colombia that strive to receive payments or compensation for their climate change mitigation results must be registered in the RENARE since the feasibility stage (Resolución 1447 [Resolution 1447], 2018). The Resolution implies that, to be eligible for offsetting, a carbon credit must not only be verified by an accredited third party but also be registered in RENARE.

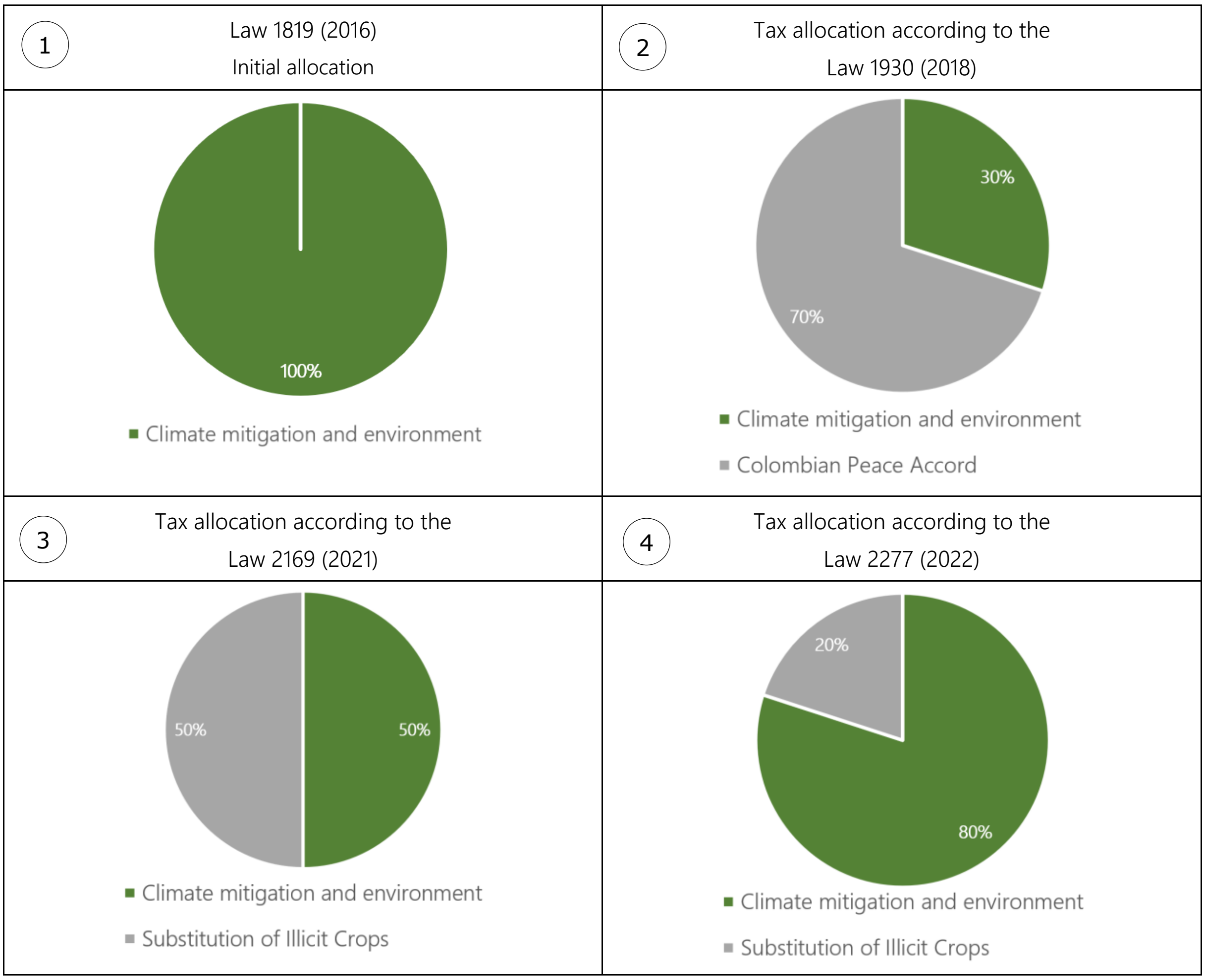
In the context of the carbon tax, the creation of RENARE would allow the Colombian government and stakeholders to consult, track, and count the number of tonnes of CO_2-eq emissions offset by taxpayers to reduce the tax burden. This would also enable the assessment of the tax's impact due to private resources directed towards incentivising greenhouse gas (GHG) reduction and elimination initiatives through the offsetting mechanism.

However, despite RENARE's intended launch in September 2018, as dictated in Resolution 1447, it was not launched until October 2019. Furthermore, RENARE has faced technical problems and has been out of service since August 2022. As of now, no provisional mechanism has replaced it. The inefficiency of RENARE has resulted in a regulatory gap and lack of transparency within the offsetting mechanism, contributing to challenges in monitoring, reporting, and verifying climate change mitigation actions within the national territory (Bermúdez, 2022). The details of the results of the offsetting mechanism are discussed in sections 6 and 7.

4.4 The allocation of the tax revenue

According to Law 1819 (2016), 100% of the tax revenue must have been directed towards coastal erosion management, water resources conservation, and ecosystem protection. However, an unexpected shift occurred with the enactment of Law 1930 by the Colombia Congress (2018), altering the initial allocation of the carbon tax to a new distribution of 30% for climate mitigation and environmental purposes and 70% designated for the Colombia Peace Accord. Three years later, Law 2169, sanctioned by the Colombian Congress (2021), reallocated the tax revenue with 50% for climate mitigation and environmental purposes and the remaining 50% for substituting illicit crops. A tributary reform introduced a last modification, Law 2277 (2022), that reallocated 80% of the tax revenue to climate mitigation and environmental purposes and 20% for substituting illicit crops. The changes in the allocation of the tax revenue over time are described in Figure 5.

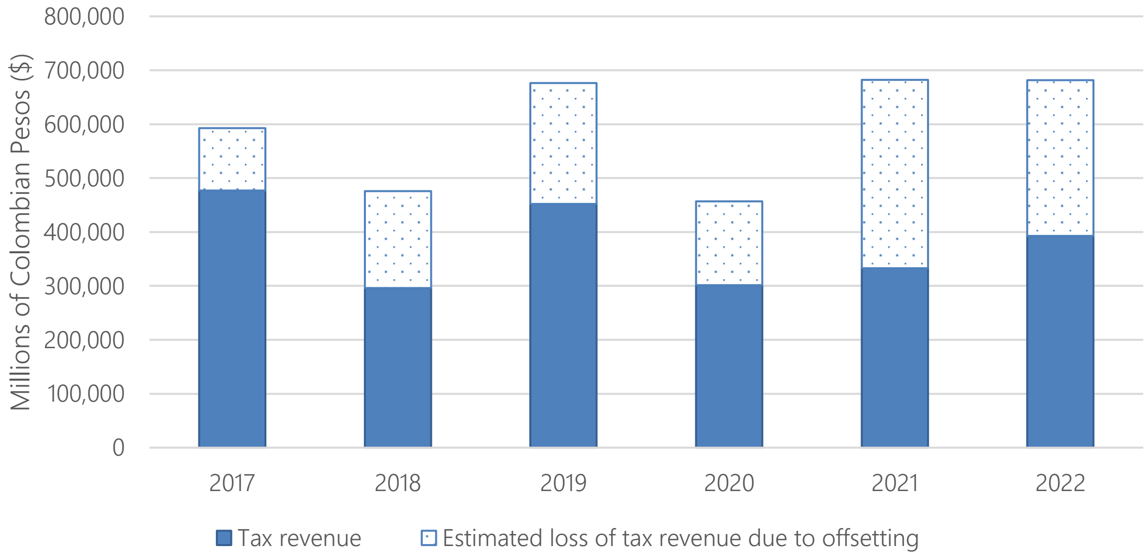
Figure 5. Carbon tax revenue allocation



Note: the figure shows the historical changes in the tax revenue allocation. Own elaboration.

From January 2017 to September 2023, the Colombian carbon tax collected $ 2,750,392 million of Colombian pesos (approximately €583,210[8]). During the observed period, the tax revenue was directly impacted by the amount of CO_2 emissions that were compensated (the more offsetting, the less tax revenue). By multiplying the actual value of the carbon tax per the tonnes of CO_2 offset annually, I estimated that the loss on tax revenue rounded 37% of the total possible revenue. The historical Colombian carbon tax revenue and estimated loss in tax revenue attributed to the offsetting mechanism are shown in Figure 6.

Figure 6. Revenue Colombian Carbon Tax plus loss in tax revenue attributed to the offsetting mechanism in millions of Colombian Pesos ($)



Note. This graphic illustrates the historical revenue of the Colombian carbon tax and the estimated loss in tax revenue attributed to the offsetting mechanism (both in millions of Colombian pesos) between 2017 and 2022.

The historical carbon tax revenue was derived by consulting tax statistics published by DIAN (2023).

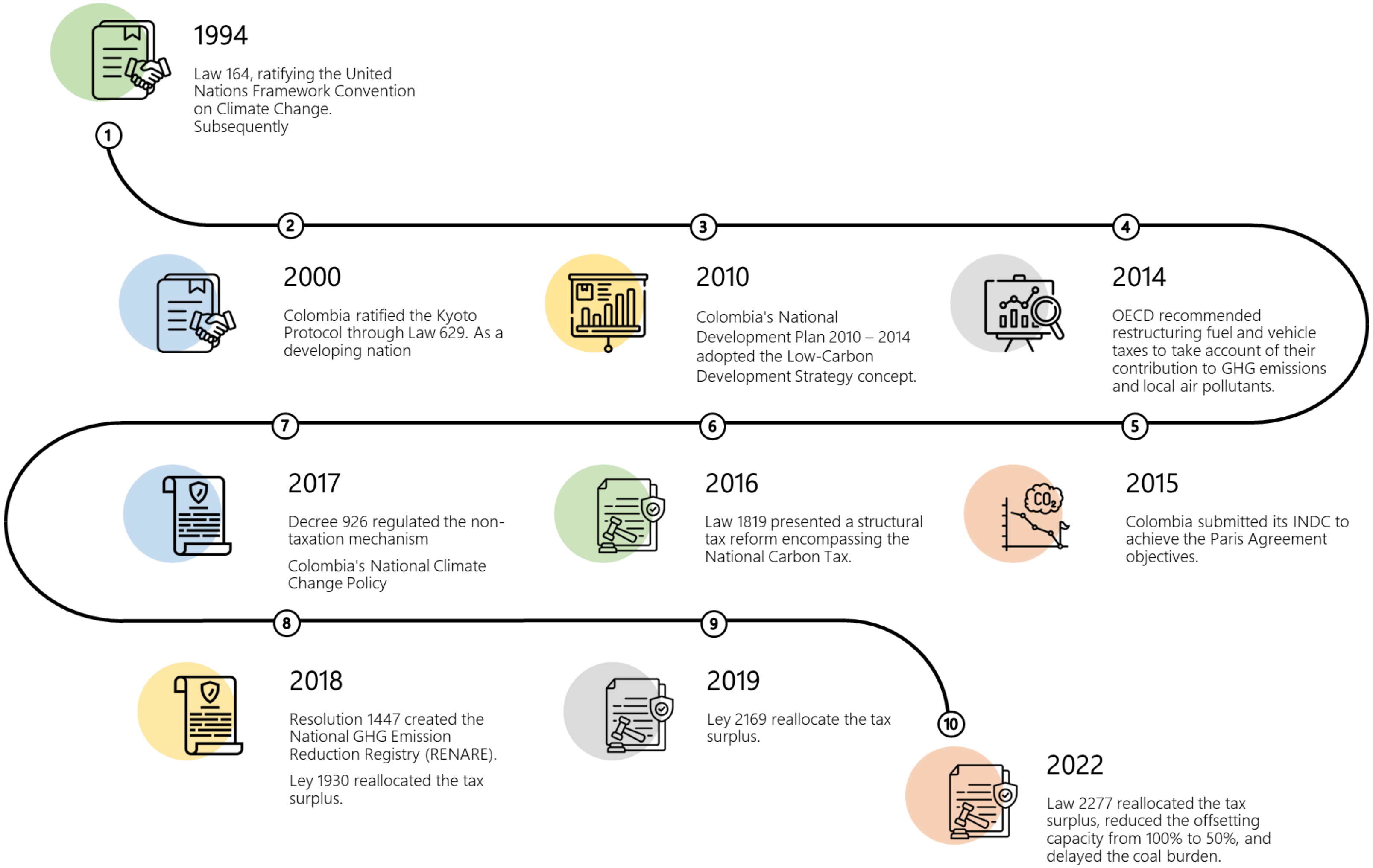
To ensure accuracy, the nominal revenue figures were adjusted to real value using the annual Consumer Price Index (CPI). The CPI data was sourced from the technical report issued by DANE (2023).

To calculate the loss of tax revenue caused by the offset mechanism, I multiplied the actual value of the carbon tax by the tonnes of CO2 offset annually. Offsetting data were obtained from the "Non-causation results bulletin" published by MADS (2023a).

To conclude this chapter, Figure *7* describes the most important events and regulations that have influenced the design and implementation of the Colombian carbon tax.

[8] This value is calculated by applying the average exchange rate in 2022 of $4,715.96 per euro.

Figure 7. Colombian Carbon Tax Timeline



Note: The figure shows the timeline with the most relevant regulations that have influenced the Colombian carbon tax and the offsetting mechanism. Own elaboration.

5 The impact of the Colombian Carbon Tax on the country's greenhouse gas emissions

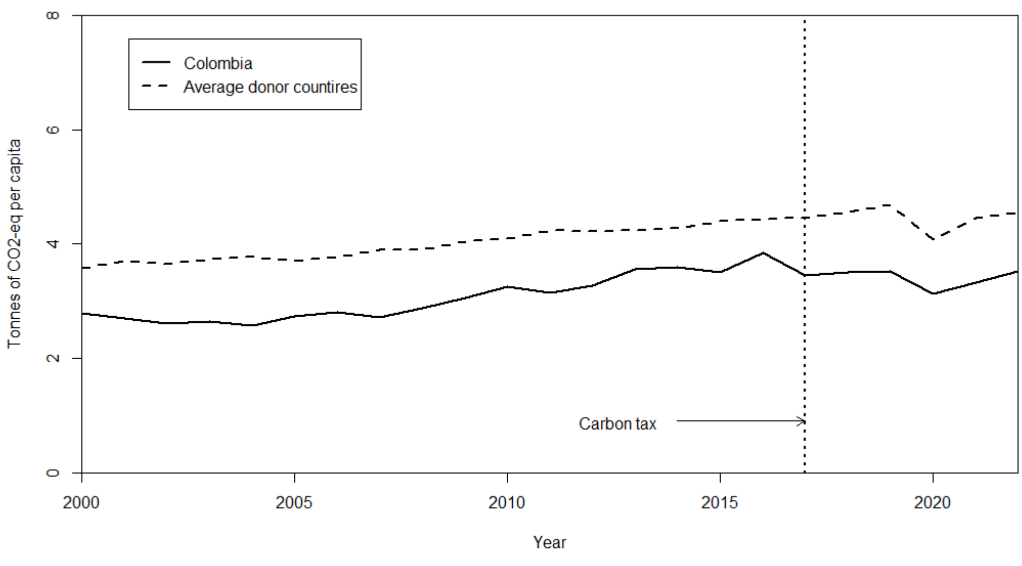
To estimate the effects of the Colombian Carbon tax, I conducted a Synthetic Control Analysis, as outlined in Section 3.2. This chapter presents the results obtained through the following steps: defining the donor pool, composing synthetic Colombia, estimating the effect of the Colombian carbon tax on national CO_2-eq emissions from fossil fuel combustion, and finally, assessing the validity of the results through the placebo test.

5.1 Selection of the donor pool

To define the donor pool, I started with all the countries from the Americas that had not implemented a carbon tax or cap-and-trade before 2022 and exhibited similarities in CO_2-eq emissions per capita from fossil fuels and GDP per capita during the pre-treatment period of 2000–2016. Consequently, 14 donor countries were included in the donor pool: Peru, Ecuador, Brazil, Panama, Costa Rica, Uruguay, El Salvador, Guatemala, Dominican Republic, Guyana, Saint Lucia, Belize, Grenada, and Saint Kitts and Nevis.

Figure 8 compares Colombia's CO_2-eq emissions per capita from fossil fuel combustion with the average of the same variable for the 14 donor countries. Before implementing the Colombian carbon tax, Colombia exhibited some similarities in the trend of CO_2-eq emissions. However, after 2017, Colombia's path displayed a reduction, possibly attributable to the implementation of the carbon tax, as discussed in sections 5.3.

Figure 8. Path plot of CO_2 emissions per capita from Colombia and average CO_2 emissions per capita of all donor countries



Note: The figure shows the trajectory of CO_2-eq emissions per capita from fossil fuel for Colombia compared to the average of the same variable for the 14 donor countries between 2000 and 2022. Own elaboration.

5.2 Synthetic Colombia

After selecting the donor countries, I conducted the synthetic analysis using the Synth R package (Abadie et al., 2011). As mentioned in section 3.2, synthetic Colombia is expected to accurately replicate CO_2-eq emissions per capita from fossil fuel combustion in Colombia during the pre-treatment period (2000 to 2016) and mirror the values of key predictors. The outcome of the synthetic analysis is determined by the weights assigned to donor countries (W) and predictors (V). Based on the available data, the optimal synthetic Colombia is a weighted average of the 14 countries in the donor pool (W), with Peru being the largest contributor at 53.4%. The details of the synthetic Colombia weights are shown in Table 3.

Table 3. Synthetic Colombia weights

Country	Weight	Cumulative weight	Country	Weight	Cumulative weight
Peru	53.4%	53.4%	Brazil	1.6%	92.8%
Dominican Republic (the)	14.6%	68.0%	Guyana	1.6%	94.4%
Panama	13.4%	81.4%	Saint Lucia	1.6%	96.0%
Guatemala	4.1%	85.5%	Ecuador	1.5%	97.5%
El Salvador	2.2%	87.7%	Grenada	1.1%	98.6%
Costa Rica	1.8%	89.5%	Uruguay	0.8%	99.4%
Belize	1.7%	91.2%	Saint Kitts and Nevis	0.5%	99.9%

Note: The table shows the weights assigned to the donor countries to create the synthetic Colombia. Own elaboration.

Moreover, the weights assigned to predictors (V) include GDP per capita (32.5%), CO_2-eq emissions per capita from all the sectors in 2000 (40.2%), 2008 (26.8%), and 2016 (0.5%). Table 4 compares the average values of key predictors for Colombia in the pre-treatment period with the same values for synthetic Colombia and donor countries. Colombia and synthetic Colombia exhibit almost the same values, demonstrating that the synthetic Colombia is an appropriate contrafactual of the actual Colombia.

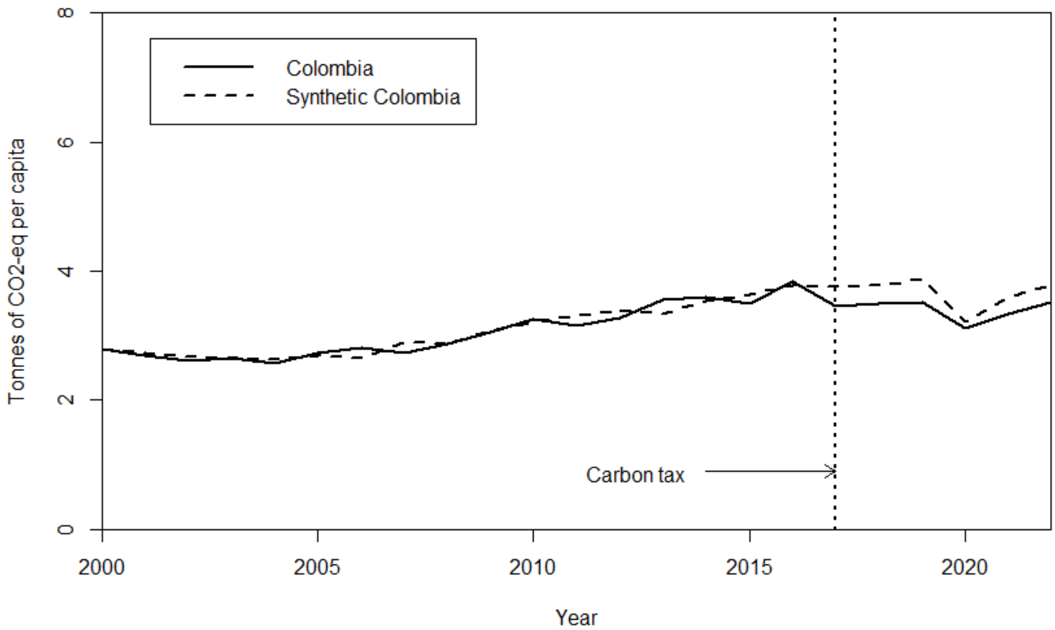
Table 4. Predictors mean before the carbon tax implementation.

	Colombia	Synthetic Colombia	Americas donor countries
GDP per capita	11423.353	11422.97	12807.845
CO_2 emissions 2000	2.795	2.795	3.586
CO_2 emissions 2008	2.870	2.872	3.895
CO_2 emissions 2016	3.843	3.770	4.445

Note: The table shows the mean GDP per capita for Colombia and Synthetic Colombia from 2000 to 2016 (pre-treatment period) and the tonnes of CO_2-eq emissions from fossil fuel combustion per capita for 2000, 2008, and 2016, which were used as special predictors. The last column shows the average of the 14 countries in the donor pool. Own elaboration.

Finally, Figure 9 illustrates the CO_2-eq emissions per capita paths for Colombia and synthetic Colombia. Before the carbon tax was implemented in 2017, Colombia and synthetic Colombia shared a similar trajectory in CO_2-eq emissions per capita from 2000 to 2016. In fact, the mean square predictor error (MSPE) between Colombia and synthetic Colombia paths in the pre-treatment period is 0.01, indicating a high degree of similarity between the two trajectories. However, after the implementation of the tax, Colombia's emission path reduces slightly with respect to the contrafactual. The MSPE in the post-treatment period is 0.07. Although the magnitude of the MSPE post-treatment seems small, it is 6.4 times larger than the pre-treatment MSPE, showing that the carbon tax and the offsetting mechanism produced an effect in Colombia's CO_2-eq emissions path.

Figure 9. Path plot per capita CO_2 emissions from fossil fuel combustion



Note: This figure compares Colombia's and synthetic Colombia's CO_2-eq emissions per capita between 2000 and 2022. It was elaborated on using the Synth R package.

5.3 The effect of the carbon tax on CO_2 emissions from fossil fuel

The introduction and gradual increase of the carbon tax led to a reduction in Colombia's CO_2-eq emissions per capita from fossil fuel combustion. The difference between the CO_2-eq emissions trajectories of Colombia and synthetic Colombia in the post-treatment period reflects the magnitude of the impact of the Colombian carbon tax. This trend is particularly noticeable from 2017 to 2019, with a potential interruption caused by the global COVID-19 pandemic. The pandemic resulted in a deceleration in the economy and, consequently, in CO_2-eq emissions for both Colombia and synthetic Colombia.

Table 5. Effect of carbon tax on Colombia's CO_2 emissions per capita from fossil fuel combustion

Year	Synthetic Colombia	Colombia	Treatment effect	% of reduction	Total treatment effect
	Tonnes CO_2 (per capita)	Tonnes CO_2 (per capita)	Tonnes CO_2 (per capita)	(%)	Tonnes CO_2 (millions)
2017	3.77	3.45	-0.32	8.4	-15.2
2018	3.77	3.50	-0.27	7.1	-13.1
2019	3.87	3.52	-0.35	9.0	-17.5
2020	3.22	3.12	-0.10	3.1	-5.1
2021	3.59	3.33	-0.26	7.2	-13.4
2022	3.77	3.52	-0.25	6.7	-13.0
Total	21.98	20.44	**-1.54**	**7.0**	**-77.4**

Note: The table shows the yearly impact of CO_2-eq emissions per capita from 2017 to 2022 resulting from implementing the carbon tax in Colombia. The last column displays the total treatment effect in millions of tonnes of CO_2-eq emissions, calculated by multiplying the treatment effect per capita by the total population of Colombia.

Upon analysing of Colombia and synthetic Colombia paths in the post-treatment period, I estimated a total reduction of 1.54 tonnes of CO_2-eq emissions per capita for the 2017-2022 period, translating to an 7.0% reduction compared to synthetic Colombia's CO_2-eq emissions. The total cumulative effect is 77.4 million tonnes of CO_2-eq emissions when aggregated over the total population. Further details of the yearly carbon tax effect are presented in Table 5.

5.4 Placebo tests and robustness

Figure 10. Placebo test in-time

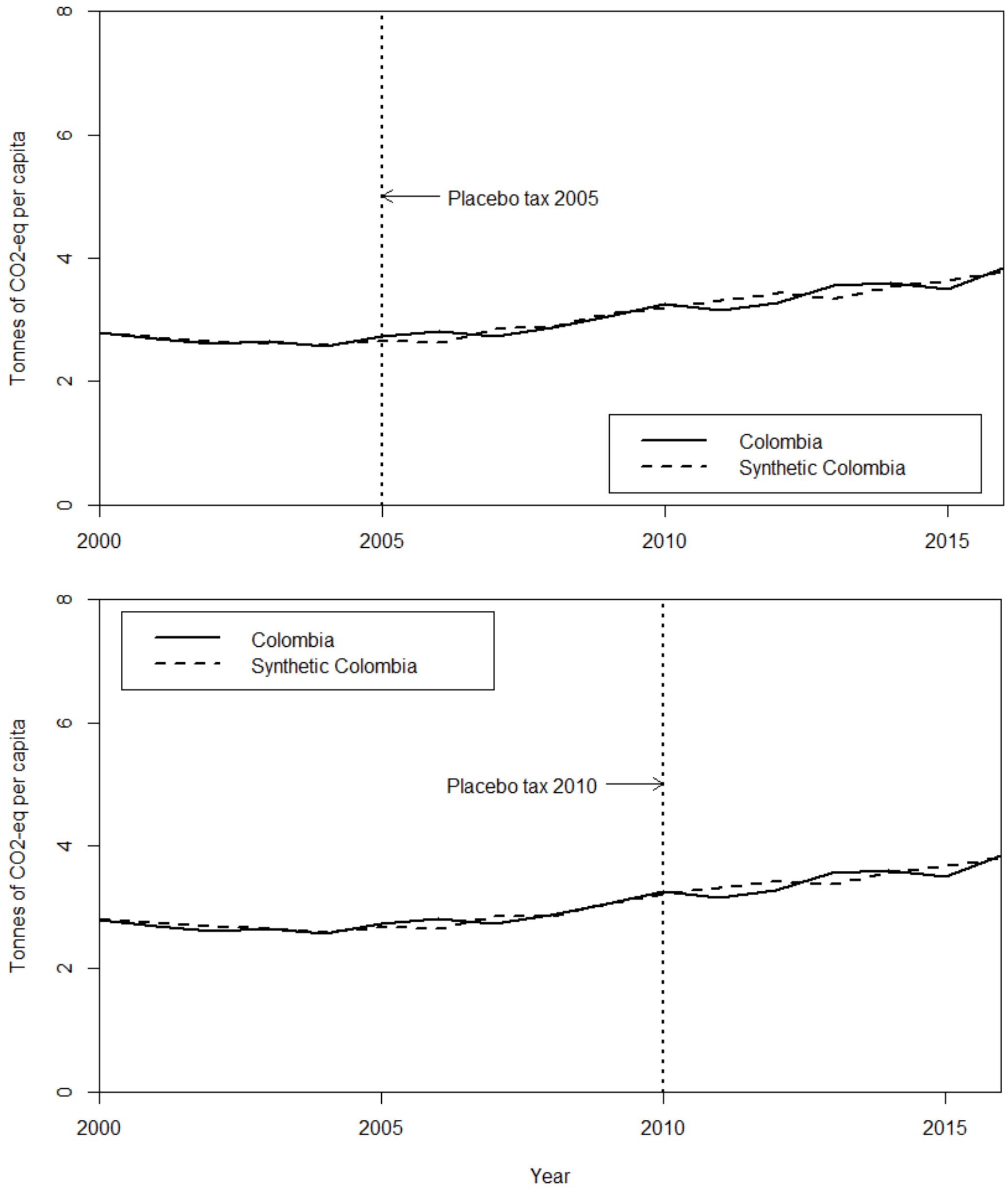


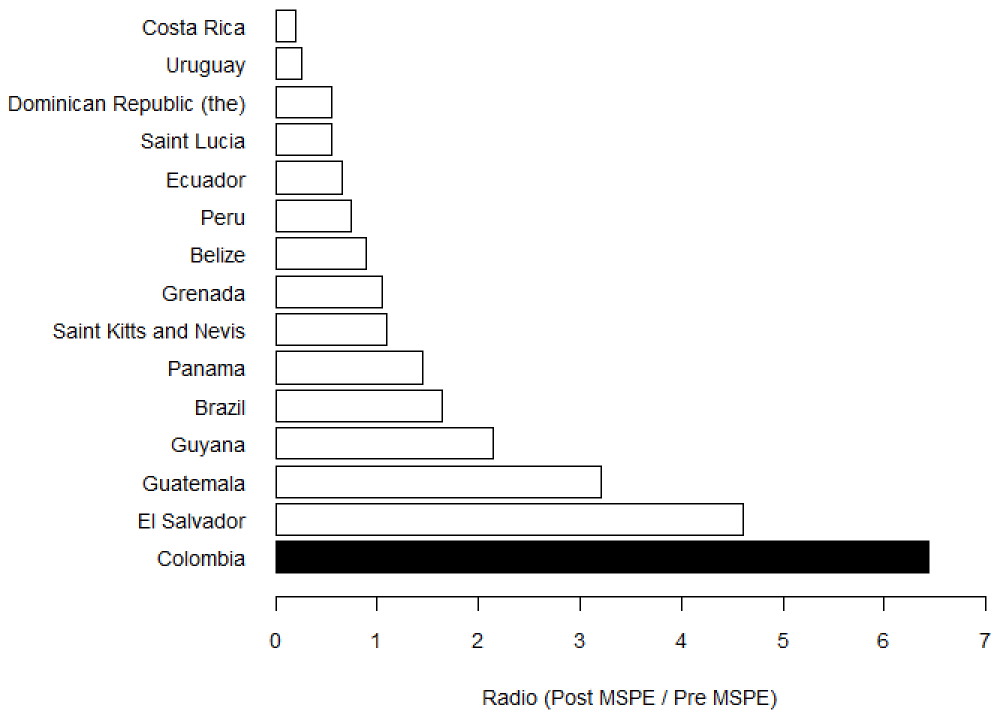
Table 6.Mean effect placebo test in time

Placebo test in-time 2005				Placebo test in-time 2010			
MSPE post	**MSPE pre**	**MSPE ratio**	**Mean effect**	**MSPE post**	**MSPE pre**	**MSPE ratio**	**Mean effect**
0.0166	0.0007	23.4469	**-0.0001**	0.0179	0.0064	2.7647	**-0.0226**

To test the credibility of the results, I conducted 'in-time' and 'in-space' placebo tests and the leave-one-out robustness test. In the 'in-time' test, the treatment year was shifted from 2016 to 2005 and to 2010. In the 'in-time' test, the treatment year was shifted from 2016 to 2005 and 2010. The results of this test indicate that Synthetic Colombia does not exhibit significant differences from Colombia in both the pre-treatment and post-treatment placebo periods for any of the placebo tax, as displayed in Figure 10. Table 6 details the numerical results of the 'in-time' test: if the treatment had taken place in 2005, its mean effect would have been -0.0001, and if the treatment had taken place in 2010, its mean effect would have been -0.0226. This suggests that the observed gap in Figure 9 truly reflects the impact of the carbon tax and not a lack of predictive power in the synthetic control.

For the in-space placebo test, I systematically assigned the treatment to each country in the donor pool to compare the estimated effects obtained for other countries. Figure 11 reveals that Colombia stands out with the largest ratio among all the samples; specifically, the post-treatment gap is 6.4 times larger than the pre-treatment gap (see Table 7). If one were to select a country from the sample randomly, the likelihood of obtaining a ratio as high as Colombia's would be 1 in 15, approximately 0.06, representing the smallest possible p-value given my sample size.

Figure 11. Ratios of post-treatment MSPE to pre-treatment MSPE for Colombia and all the countries in the donor pool



Note: The figure shows the MSPE ratios obtained by iteratively assigned the treatment to each country in the donor pool.

Table 7. Ratios of post-treatment MSPE to pre-treatment MSPE

Country	Ratio	Country	Ratio	Country	Ratio
Colombia	6.4	Panama	1.4	Ecuador	0.7
El Salvador	4.6	Saint Kitts and Nevis	1.1	Saint Lucia	0.6
Guatemala	3.2	Grenada	1.1	The Dominican Republic	0.6
Guyana	2.1	Belize	0.9	Uruguay	0.3
Brazil	1.6	Peru	0.8	Costa Rica	0.2

Finally, I conducted the leave-one-out test to evaluate the sensitivity of the results for the 14 countries that obtained weights in the synthetic control. Figure 12 displays the Colombia CO_2-eq emissions path in a solid black line, the synthetic Colombia obtained with the original donor pool in black dashed lines, and the 14 alternative CO_2-eq paths obtained by the leave-one-out test in grey.

Overall, in all iterations, a causal effect in the post-treatment period induced by the carbon tax is evident; this confirms that the results are robust to the exclusion of any particular country from the sample. The smallest carbon tax effects are observed when comparing Colombia's CO_2-eq emissions with a synthetic Colombia produced by a donor pool without Peru (6.25%) and the biggest effect is observed with a donor pool without Guatemala (8.50%), but these effects are not substantially different from the effect calculated for the synthetic test, which is 7.01%. The details of the leave-one-out test are shown in Table 8.

Figure 12. Leave-one-out placebo test of the synthetic control of Colombia

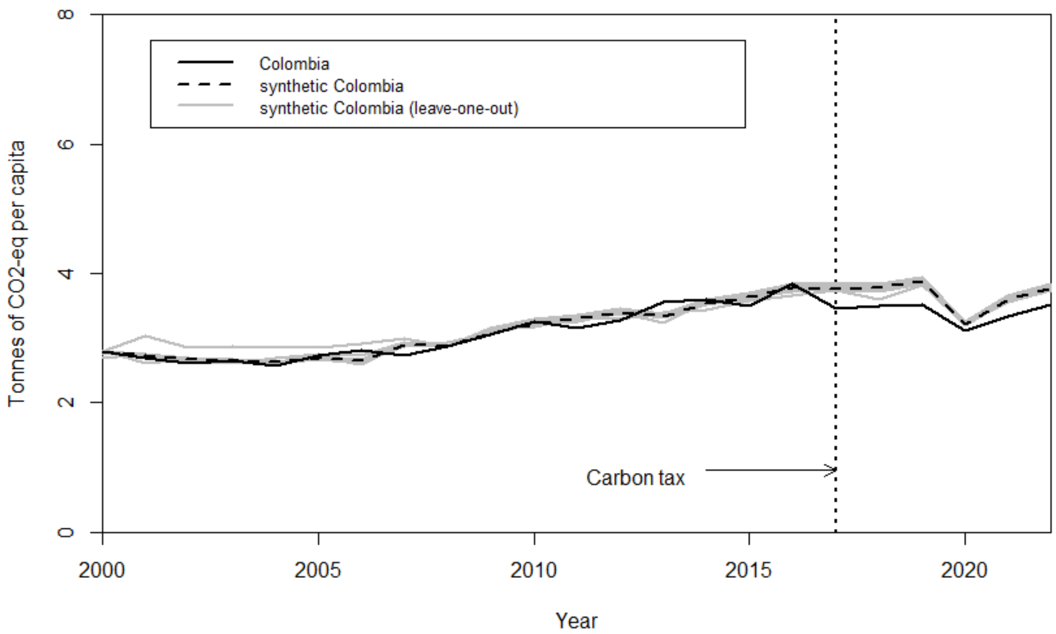


Table 8. Leave-one-out-test percentage reduction

Leave-one-out test	Total treatment effect	Percentage reduction	Leave-one-out test	Total treatment effect	Percentage reduction
	Tonnes CO_2 (per capita)	(%)		Tonnes CO_2 (per capita)	(%)
No Peru	-1.36	6.25	No Panama	-1.55	7.03
No Saint Lucia	-1.39	6.38	No Grenada	-1.55	7.07
No Saint Kitts	-1.43	6.55	No Ecuador	-1.57	7.14
No Guyana	-1.47	6.69	No Brazil	-1.58	7.19
No Dominicana Rep	-1.52	6.90	No Costa Rica	-1.63	7.40
No Belize	-1.54	6.99	No Uruguay	-1.85	8.29
No El Salvador	-1.54	7.00	No Guatemala	-1.90	8.50
All the donor pool	**-1.54**	**7.01**			

The results presented in this chapter can be reproduced using the R scripts detailed in Appendix 1. Carbon tax_Colombia.

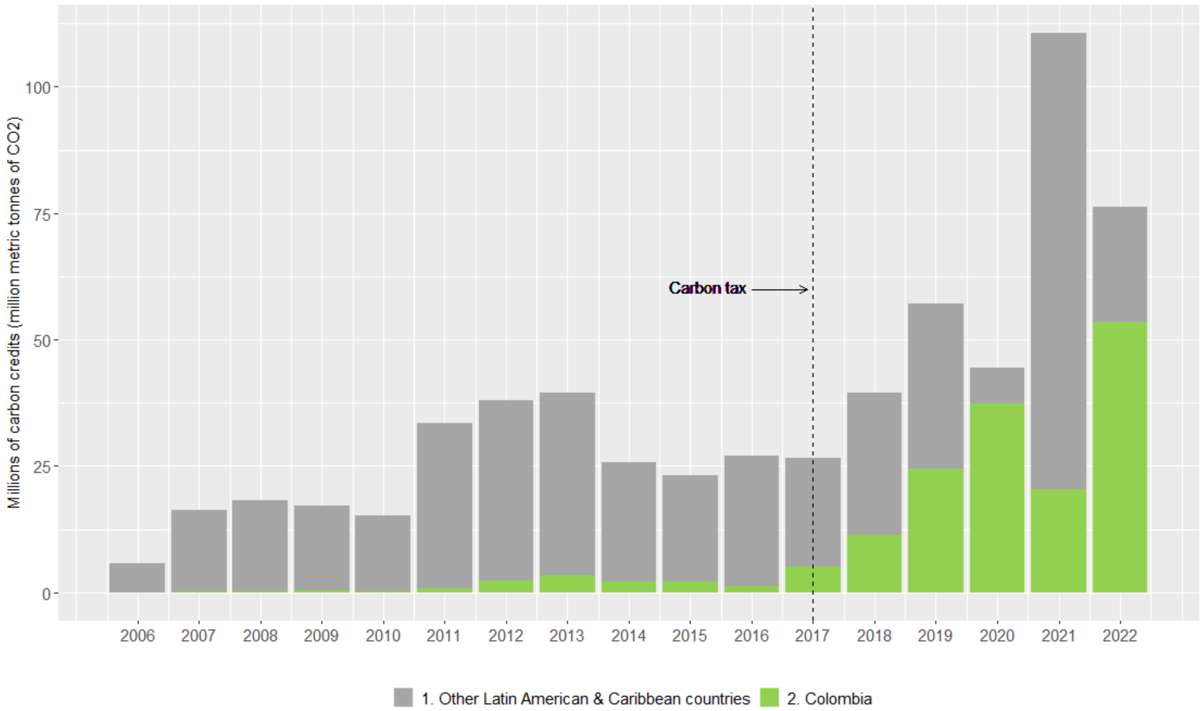
6 The impact of the offsetting mechanism on the carbon crediting market in Colombia

After collecting data on the carbon credits issued and cancelled in Colombia, I built consolidated databases for issuances, cancellations, and carbon tax offsets. This was useful for performing an empirical analysis to assess the impact of the offsetting mechanism on the carbon crediting market. This chapter describes the changes observed in the Colombian Carbon Market, from the supply and demand side, after the carbon tax implementation.

6.1 Supply side - Colombian carbon market issuances

While carbon crediting markets are growing globally, as described by the World Bank Group (2023), the Colombian carbon crediting market has "exploded" following the implementation of the carbon tax. Figure 13 illustrates the historical issuance of carbon credits in Latin America and the Caribbean, highlighting Colombia's remarkable contribution. Between 2016 and 2022, Colombia's share of the Latin American market skyrocketed from 5% to 70%, as depicted in Table 9. This growth underlines Colombia's emergence as a dominant player in the region's carbon credit landscape, specifically following the implementation of the carbon tax.

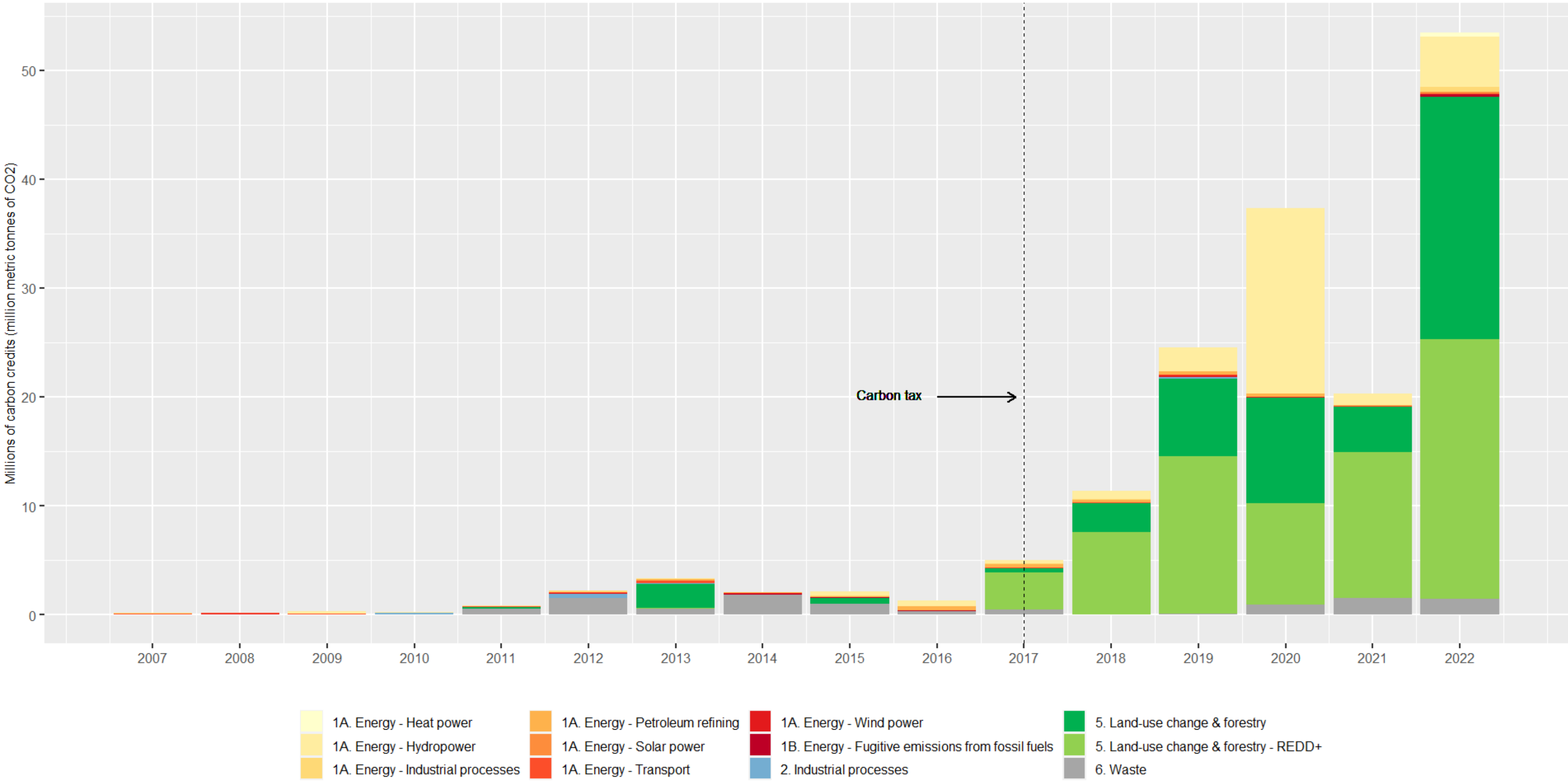
Figure 13. historical issuances in Latin America & Caribbean



Note: Figure shows the issuances of carbon credits in Latin America & Caribbean, highlighting Colombia participation. The data on Colombia's carbon credit issuances were gathered by consulting all available carbon credit registries, as detailed in section 3.3 (highlighted in green). Meanwhile, the issuance figures from other countries in the region (depicted in grey) were estimated by subtracting Colombia's carbon credit issuances from the total Latin America & Caribbean carbon credit issuances reported by the (World Bank Group, 2023b)

Before 2017, carbon credit issuances in Colombia were notably low compared to the period following the tax's introduction. In the pre-2017 period, credits were primarily generated from projects related to waste treatment and energy production, with the exception of 2013, when the first credits for reforestation were issued. Following the implementation of the carbon tax, there was a substantial rise in credit issuance, particularly in forest credits (REDD+ and non-REDD+) and energy generation credits, mainly from small and medium hydroelectric sources. Other sectors issuing carbon credits included waste, petroleum refining, and transport, among others (refer to Figure 14).

Figure 14. Historical issuances of carbon credits in Colombia by sector.



Note. This graphic shows the historical issuances of carbon credits (millions of carbon credits) in Colombia by sectoral reduction. I obtained the data by consulting all the carbon credit registries available, as described in the section 3.3.

Table 9. Carbon credit issuances in Colombia vs other countries in Latin America & Caribbean

Year	Other countries in Latin America & Caribbean	Colombia	Total issuances Latin America & Caribbean	Share of issuances supply by Colombia
	Millions of tonnes of CO_2	Millions of tonnes of CO_2	Millions of tonnes of CO_2	(%)
2003	0.05	0.00	0.05	0%
2004	0.04	0.00	0.04	0%
2005	0.10	0.00	0.10	0%
2006	5.68	0.00	5.68	0%
2007	16.23	0.15	16.38	1%
2008	18.04	0.14	18.18	1%
2009	16.87	0.30	17.17	2%
2010	15.00	0.24	15.23	2%
2011	32.55	0.86	33.40	3%
2012	35.77	2.22	37.99	6%
2013	36.18	3.31	39.50	8%
2014	23.76	2.05	25.81	8%
2015	20.96	2.11	23.06	9%
2016	25.76	1.26	27.02	5%
2017	21.65	5.02	26.67	**19%**
2018	28.09	11.38	39.47	**29%**
2019	32.62	24.53	57.15	**43%**
2020	7.02	37.32	44.34	**84%**
2021	90.44	20.27	110.70	**18%**
2022	22.68	53.50	76.17	**70%**

Between 2007 and 2016, only 12.6 million carbon credits were issued. In contrast, from 2017 to 2022, 164.6 million carbon credits were issued, accounting for 92% of all carbon credits historically issued in Colombia. This trend is particularly evident in specific sectors. For instance, 99.9% of REDD+ credits, 94% of other afforestation and reforestation projects, 94.8% of energy generation through hydroelectric sources, and 100% of energy generation through solar and heat power occurred post-implementation, as detailed in Table 10.

It is important to note that all projects classified as '1A. Energy' in Table 10 may pertain to economic activities subject to the carbon tax. As a result, these projects could already be financially viable even without relying on revenue from carbon credit sales, thus making them non-additional. For instance, projects classified as '1A. Energy - Heat power' and '1A. Energy - Petroleum refining' are optimisations of processes to use less fossil fuel rather than replace the current fuel with renewable alternatives. In addition, '1A. Energy - Hydropower power' credits are mostly large-scale hydroelectric power plants. I discuss the implications of this situation in sections 7 and 8.

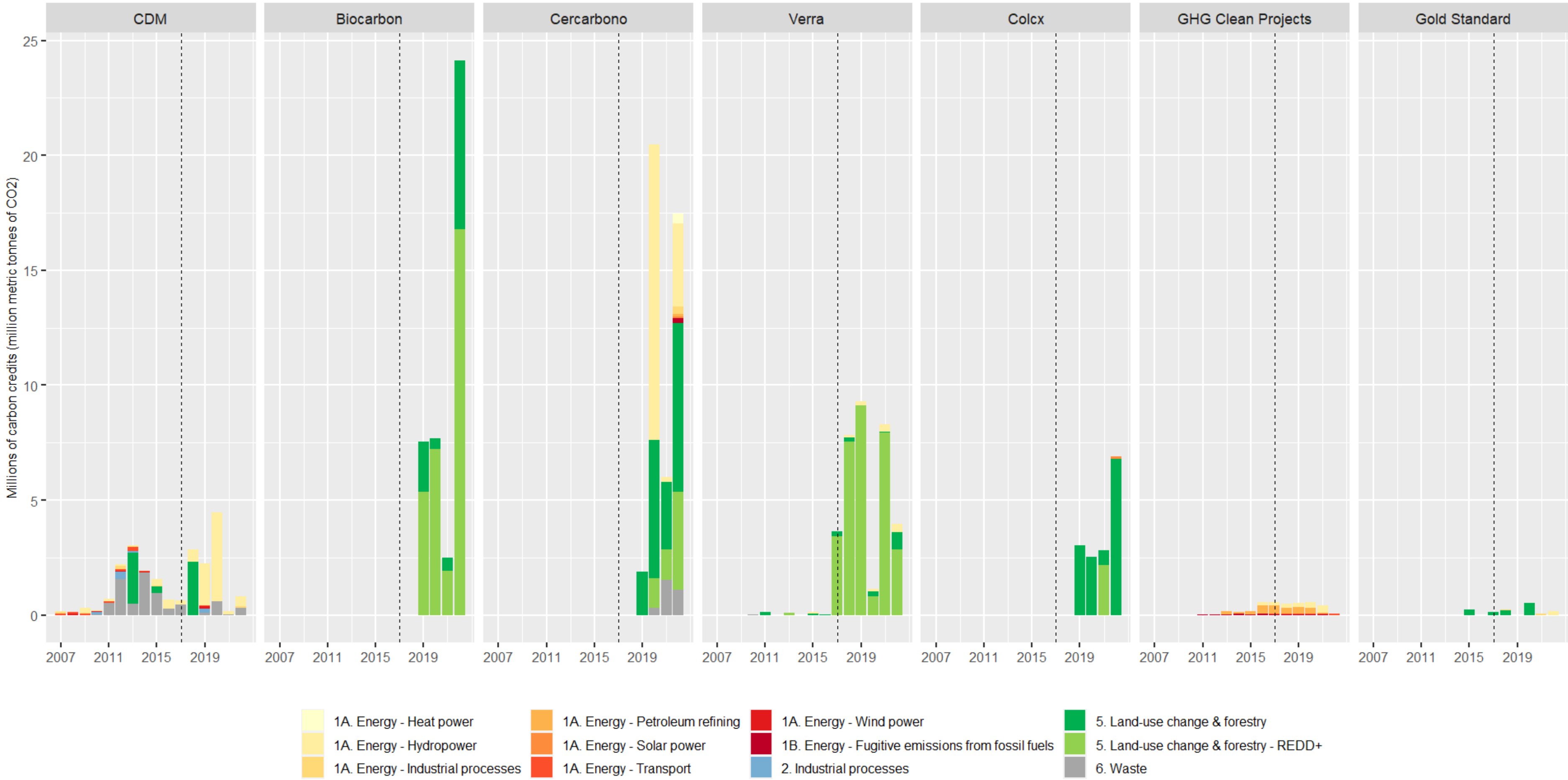
Table 10. Carbon credits issued in Colombia by type of project.

Project classification by source/sink	**Credits issued 2007-2016**	**Credits issued 2017-2022**	**Total credits issued**	**Share 2017-2022**	**Share from the total issued**
	Millions of tonnes of CO_2	Millions of tonnes of CO_2	Millions of tonnes of CO_2	(%)	(%)
5. Land-use change & forestry - REDD+	0.10	72.04	72.14	**99.9%**	43.8%
5. Land-use change & forestry	2.96	46.28	49.23	**94.0%**	29.9%
1A. Energy - Hydropower	1.45	25.93	27.38	**94.7%**	16.6%
6. Waste	5.70	4.42	10.12	43.7%	6.1%
1A. Energy - Petroleum refining	0.70	1.31	2.01	65.3%	1.2%
1A. Energy - Transport	0.57	0.32	0.90	36.2%	0.5%
1A. Energy - Industrial processes	0.29	0.51	0.80	63.5%	0.5%
2. Industrial processes	0.53	0.19	0.72	26.9%	0.4%
1B. Energy - Fugitive emissions from fossil fuels	0.19	0.28	0.48	59.7%	0.3%
1A. Energy - Wind power	0.15	0.14	0.29	46.9%	0.2%
1A. Energy – Heat power	0.00	0.42	0.42	**100.0%**	0.3%
1A. Energy - Solar power	0.00	0.16	0.16	**100.0%**	0.1%
Total issuances	**12.64**	**152.01**	**164.64**	**92%**	**100.0%**

Note: The table displays the amount of carbon credits emitted between 2007 and 2016 and between 2017 and 2022. The column 'Share 2017-2022' calculates the proportion of carbon credits emitted between 2017 and 2022 relative to the total credits emitted historically in Colombia, while the last column indicates the proportion of credits issued for each project classification relative to the total credits issued historically. The data were obtained by consulting all available carbon credit registries, as described in section 3.3.

A final consideration regarding the supply side of the carbon market pertains to the crediting mechanism. Before the implementation of the carbon tax, Colombia heavily relied on international mechanisms such as the Clean Development Mechanism (CDM) to issue carbon credits, accounting for 86.4% of all credits issued in the country. However, after the tax took effect, independent mechanisms such as Vera, Biocarbon, Cercarbono, and Colcx emerged as the primary suppliers of carbon credits. Consequently, international mechanisms contributed only 7.3% of the total credits issued between 2017 and 2022. Figure 15 illustrates the historical participation of each carbon crediting program in the Colombian carbon crediting market.

Figure 15. Historical issuances of carbon credits in Colombia by sector and carbon crediting program.

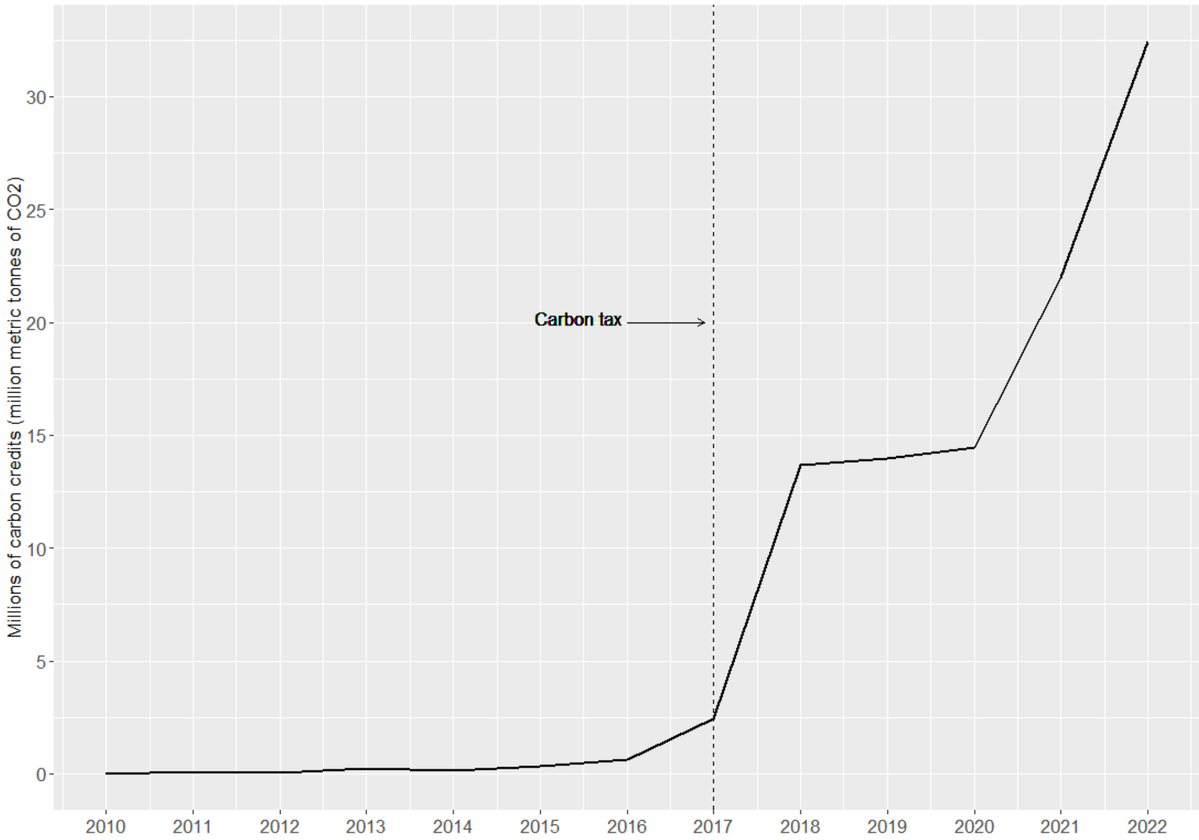


Note: This graphic shows the historical issuances of carbon credits (millions of carbon credits) in Colombia by sectoral reduction and carbon crediting program. I obtained the data by consulting all the carbon credit registries available as described in section 3.3.

6.2 Demand side - Colombian carbon market cancellations.

After the implementation of the Colombian carbon tax, there was a significant increase in carbon credit cancellations. While the first cancellations in the Colombian carbon crediting market were recorded in 2010, the volume of carbon credits purchased remained relatively low until 2016 (refer to Figure 16). In total, 60.9% of all credits issued historically in Colombia have been cancelled: 0.8% in the pre-implementation period and 60.1% in the post-implementation period.

Figure 16. Historical carbon credits cancellations in Colombia

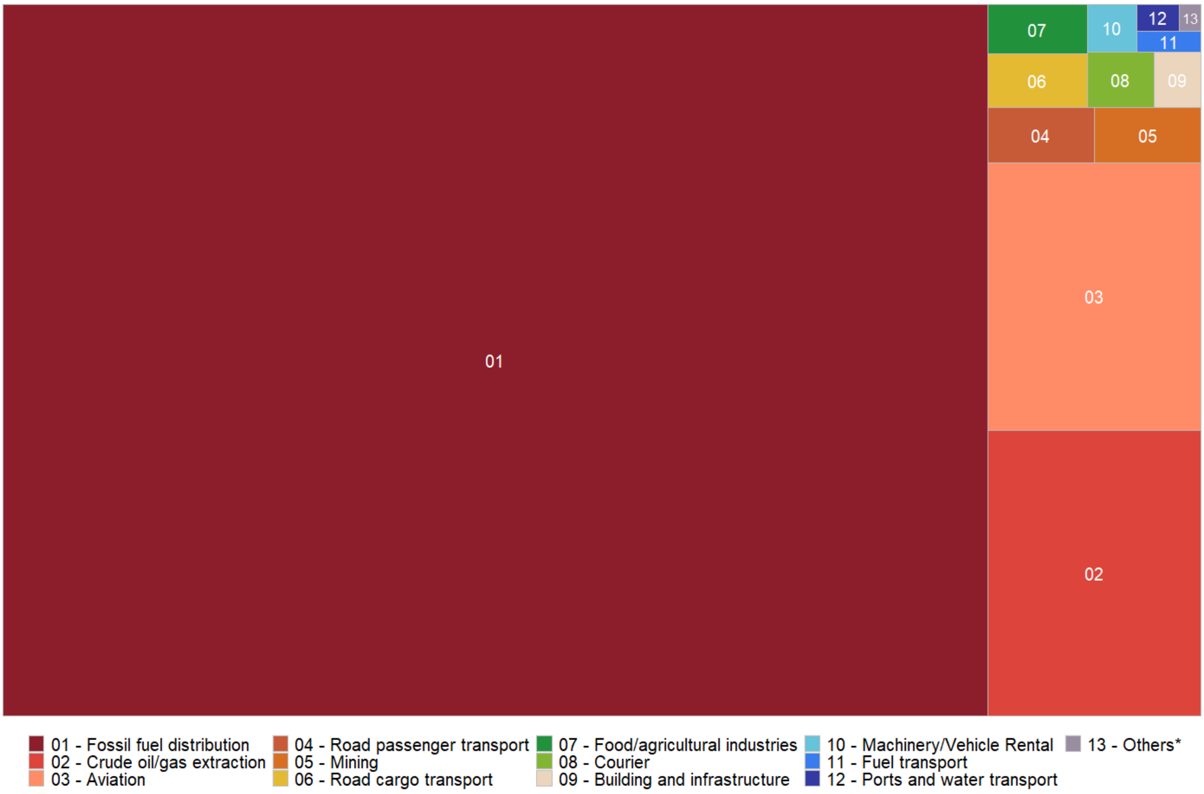


Note: This graphic shows the historical carbon credit cancellations in Colombia (millions of carbon credits). I obtained the data by consulting all the carbon credit registries available, as described in section 3.3

On the other hand, according to the database provided by MADS (2024), the highest demand for carbon credits for offsetting purposes came from economic activities such as fossil fuel distribution, followed by oil/gas extraction and aviation, as shown in Figure 17. The smallest shares of demand for carbon credits with offsetting purposes came from road passenger transport, mining, road cargo transport, and other economic activities.

The fact that offsetting is mainly done by fossil fuel distribution is coherent because the carbon tax is charged during the purchase or importation. However, it is also worth noting that, in general, fossil fuel distribution does not produce significant emissions directly from the process. Therefore, the offsetting by fossil fuel distributors does not necessarily represent emissions that cannot be avoided with currently available and affordable technology, but rather, it serves as a direct reduction of the carbon tax signal.

Figure 17. Economic activities that applied to the offsetting mechanism



** Other activities: Food and beverage trade, domestic public utilities, auto parts trade, chemical industry, wood industry, management consulting.*

Note: The graphic represents the economic activities that applied to the offsetting mechanism between 2017 and 2022. I obtained the data from the offset dataset provided by the MADS.

Finally, I analysed whether there were any preferences for carbon credits to offset in order to claim carbon tax exemption. Figure 18 illustrates the correlation between economic activities subject to the carbon tax and sectors that issued carbon credits. In general, forest credits (REDD+ and non-REDD+) and hydropower were commonly used for offsetting across various economic activities, consistent with their prevalence in the Colombian carbon crediting market. However, crude oil/gas extraction displayed a different trend. Most offsetting occurred with carbon credits issued in projects reducing emissions primarily in the '1A. Energy – petroleum refining' sector (filled in bright orange in Figure 18).

Nevertheless, I found that both the proponent of the project and purchaser of the credits were the primary petroleum company in Colombia, Ecopetrol. Furthermore, the carbon credits were issued after the implementation of an energy efficiency improvement project in a single refinery located in Barrancabermeja, resulting in reduced fuel gas consumption. Given that the carbon tax affects gas consumption, the additionality of the project is questionable, as is the transparency of the offsetting mechanism. I discuss the implications of this situation in sections 7 and 8.

The databases issuances, cancellations, and carbon tax offsets are presented in Appendix 2. Colombian carbon crediting market.

Figure 18. Sectors that issued carbon credits vs. economic activities that offset to claim offsetting of the carbon tax.

Note: The graph illustrated some correlation patterns between economic activities affected by the carbon tax and the sectors where offsetting occurred. Economic activities that offset to claim non-causation of the carbon tax are represented on the right-hand side, while sectors that issued carbon credits between 2017 and 2022 are shown at the top of the graph. Own elaboration.

**Other economic activities: Road passenger transport, mining, road cargo transport, food/agricultural industries, courier, building infrastructure, machinery/vehicle rental, fuel transport, ports and water transport, food and beverage trade, domestic public utilities, auto parts trade, chemical industry, wood industry, management consulting.*

***Other sectors: Energy – Heat power, Energy – Transport, Energy - Industrial processes, Industrial processes, Energy - Fugitive emissions from fossil fuels, Energy - Wind power, Energy - Solar power.*

7 The integrity of the Colombian carbon crediting market

To evaluate the integrity of the Colombian crediting market, I conducted an analysis of databases pertaining to issuances, cancellations, and offsets, focusing on aspects of additionality, permanence, and double counting. The assessment started with a compilation of findings from prior studies regarding the additionality of REDD+ projects in Colombia. Subsequently, an examination was undertaken of projects that issued credits in the 1A Energy sector, finishing with an evaluation of the accounting control of the offset mechanism.

7.1 The additionality of REDD+ projects

The efficacy of 10 REDD+ projects hosted in Colombia was appraised in two scientific studies. These studies examined the additionality and credible baselines of land-use change and forestry projects. Guizar-Coutiño et al. (2022) evaluated 40 REDD+ projects certified by Verra, which included 10 projects hosted in Colombia. Their evaluation, based on pixel matching, suggested that, overall, REDD+ interventions reduced deforestation and degradation in most of the projects assessed. Specifically in Colombia, 8 out of the 10 projects reduced the deforestation rate, with reductions ranging from 52.6% to 5.3%. However, one project did not demonstrate a reduction, and two projects actually increased the deforestation rate by 108% and 228% (see Table 11).

Table 11. Reduced deforestation in 10 REDD+ projects in Colombia estimated by Guizar-Coutiño et al. (2022)

Project ID	Project name	Deforestation rate
856	The Chocó-Darién Conservation Corridor REDD Project	-53%
1399	Mutatá REDD+ Project	-25%
1391	SIVIRÚ-USARAGÁ-PIZARRO-PILIZÁ (SUPP) REDD+ Project	-50%
1389	Acapa -- Bajo Mira Y Frontera REDD+ Project	-12%
1400	Concosta REDD+ Project	-50%
1392	Cajambre REDD+ Project	-33%
1395	Bajo Calima y Bahía Málaga (BCBM) REDD+ Project	-5%
1566	REDD+ Project Resguardo Indigena Unificado Selva de Mataven	+108%
1396	Rio Pepe y ACABA REDD+ Project	0%
1390	Carmen del Darién REDD+ Project	+229%

Note: I constructed this table based on the supplementary material from Guizar-Coutiño et al. (2022) *paper.*

Furthermore, West et al. (2023) investigated the effectiveness of avoiding deforestation in 26 REDD+ projects, 6 of which were located in Colombia, using a synthetic control approach for causal inference. All of the Colombian REDD+ projects analysed in this paper were previously analysed by Guizar-Coutiño et al. (2022). The findings of West et al. (2023) revealed that only three of the Colombian projects evaluated achieved deforestation reductions, although not to the extent claimed by Verra as detailed in Table 12.

The apparent discrepancy between the findings of the two papers arises from differences in methodological approaches and study timeframes. Additionally, while Guizar-Coutiño et al. (2022) focus solely on assessing the reduction in deforestation rates following the implementation of REDD+ projects, West et al. (2023) also evaluate the consistency between the carbon credits emitted by Verra and the corresponding reforestation rates. West et al. (2023) attribute the observed differences to the discrepancy between the initial high deforestation rates (baselines) assumed by Verra and the actual rates. Consequently, carbon offsets may not reflect actual emission reductions; in other words, carbon credits from the evaluated REDD+ projects lack additionality.

Table 12. Carbon credits claim by Verra vs. Carbon credits estimated by West et al.

Project ID	**Project name**	**Expected carbon offset (Verra)**	**Expected carbon offset (West et al.)**
		Mg CO_2	Mg CO_2
1400	Concosta REDD+ Project	1,657,098	0
1566	REDD+ Project Resguardo Indigena Unificado Selva de Mataven	31,325,923	0
1396	Rio Pepe y ACABA REDD+ Project	1,489,786	601,008
1395	Bajo Calima y Bahía Málaga (BCBM) REDD+ Project	2,791,723	252,149
1391	SIVIRÚ-USARAGÁ-PIZARRO-PILIZÁ (SUPP) REDD+ Project	1,548,059	0
1392	Cajambre REDD+ Project	1,455,141	15,954

Note: I take this data from the supplementary material from West et al. (2023) paper.

7.2 Removals and reductions in 1A Energy source/sink

The carbon tax in Colombia imposes a levy on the consumption of fossil fuels within the national territory. In line with the IPCC (1997) classification, the carbon tax targets emissions in the '1A Energy sector'. Considering that according to TSVCM (2021), demonstrating additionality always requires that the avoidance or reduction of emissions exceed those required by relevant legal requirements, the issuance of carbon credits after the implementation of the carbon tax in the '1A Energy sector' may require careful scrutiny by crediting programs. As indicated in Table 13, 19.4% of the reductions or removals in the Colombian carbon crediting market were claimed within the same sector, primarily through 1A. Energy – Hydropower (16.9%).

Table 13. Issuances in the Colombian carbon crediting market

Project classification by source/sink	**Total projects**	**Total credits issued**	**Percentage**	**Cumulative percentage**
		Millions of tonnes of CO_2	%	%
1A. Energy – Heat power	1	0.42	0.3%	0.3%
1A. Energy - Hydropower	41	27.38	16.6%	16.9%
1A. Energy - Industrial processes	8	0.80	0.5%	17.4%
1A. Energy - Petroleum refining	2	2.01	1.2%	18.6%
1A. Energy - Solar power	6	0.16	0.1%	18.7%
1A. Energy - Transport	4	0.90	0.5%	19.2%
1A. Energy - Wind power	1	0.29	0.2%	19.4%
1B. Energy - Fugitive emissions from fossil fuels	4	0.48	0.3%	19.7%
2. Industrial processes	2	0.72	0.4%	20.1%
5. Land-use change & forestry	107	49.23	29.9%	50.0%
5. Land-use change & forestry - REDD+	37	72.14	43.8%	93.9%
6. Waste	15	10.12	6.1%	100.0%
Total	**227**	**164.64**	**100.0%**	

Note: The table shows the number of projects that claimed reductions or removals in the Colombian carbon crediting market, along with the percentage of carbon credits and the proportion each classification represents.

Under the classification '1A. Energy – Hydropower', both large and small hydroelectric projects have claimed reductions and avoidance of CO_2 emissions, collectively representing 16.9% of the total credits issued in the Colombian carbon crediting market. In my analysis, I focused on 10 out of 41 hydroelectric projects, which accounted for 89.9% of the credits historically issued under this classification (refer to Table 13).

To conduct this analysis, I gathered information from publicly available documentation for each project, including details such as the opening year, size, and years of credit issuance. The analysis revealed that nine of the 10 hydroelectric projects claiming CO_2 emissions reduction or avoidance were classified as large hydroelectric projects. Eight of these projects were commissioned many years before the implementation of the carbon tax, with six of them issuing credits after the tax implementation (highlighted in red lettering in Table 14). These six projects collectively account for 79.6% of the total credits issued under the category '1A. Energy – Hydropower'. This finding is consistent with section 6.1, where it was established that 94.7% of the total credits in this category were issued after the implementation of the carbon tax. However, considering that the majority of the credits come from pre-existing projects, all of which are large hydroelectric, assessing additionality from an investment perspective—i.e., whether carbon credits sold revenue are necessary to make the project economically attractive and viable—may not be applicable in this case. Moreover, given that 75.3% of Colombia's electricity has been generated through large hydroelectric projects since 2013 (Cogaria, 2019), the additionality from the market penetration approach is also not applicable.

Table 14. Hydropower projects in the Colombian crediting market

Project name	**Size**	**Total credits issued**	**Percentage**	**opening year**	**Credits issuance years**
		Millions of tonnes of CO_2	%		
Porce III Hydroelectric Project	Large	11.09	40.5%	2010	2020 - 2022
Sogamoso Hydroelectric Project	Large	4.38	16.0%	2014	2019 - 2020
El Quimbo Hydroelectric Project	Large	3.27	11.9%	2015	2020 - 2022
Dario Valencia Samper Hydroelectric Project	Large	1.45	5.3%	1973	2020 - 2022
Carlos Lleras Restrepo Hydroelectric	Large	1.13	4.1%	2015	2015 - 2022
La Vuelta and La Herradura Hydroelectric	Large	1.06	3.9%	2004	2009 - 2022
Rio Amoya Run-of-River Hydro Project	Large	1.01	3.7%	2013	2016 - 2022
El Molino-San Matias hydroelectric projects	Small	0.37	1.3%	2017	2022
Cucuana Hydroelectric Power Plant	Large	0.35	1.3%	2011	2019 - 2020
Hydroelectric Project PCH Luzma	Large	0.27	1.0%	2017	2020 - 2021
Tequendama Hydroelectric Project	Large	0.26	0.9%	2018	2020 - 2022
Other hydropower projects no analysed		2.75	10.1%		
Total		**27.38**	**100%**		

In the '1A. Energy - Petroleum refining', two projects have claimed reductions. These projects involve the implementation of energy efficiency improvements in refineries located in Barrancabermeja and Cartagena, owned by Ecopetrol, resulting in reduced fuel and gas consumption. According to publicly available information from the GHG Clean Registry (2024), the project located in Barrancabermeja was implemented in 2013 and had issued credits since then to 2021. Furthermore, Ecopetrol, the project proponent and buyer of the carbon credits, has retired 1.4 million out of 1.9 million carbon credits to offset in order to reduce the carbon tax burden.

On the other hand, the Cartagena refinery project was implemented and certified reductions of CO_2 emissions in 2022 by improving the efficiency of fossil fuel consumption, five years after the implementation of the carbon tax in the same sector targeted by the tax. Although these credits have not been retired yet, they are likely to be used again by Ecopetrol to avoid the tax burden.

In the '1A. Energy – Heat power' classification, a similar project aimed at reducing emissions was implemented. This project involved a series of energy efficiency improvements in an energy production plant based on natural gas and diesel, starting in 2017, coinciding with the introduction of the carbon tax. The fact that the carbon tax might influence the decision to implement such projects not only raises concerns about compliance with additionality criteria but also underscores the ambiguous effect of the offsetting mechanism. While the offsetting mechanism reduces the price signal effect of fossil fuel-based products from the targeted sector, it theoretically leads to overall emissions reductions in the same sector. However, its effect in these cases overlaps with the carbon tax, further complicating the assessment of its impact.

7.3 Offsetting to avoid carbon tax vs cancellations

I compared the cancellations database that I constructed from the available information in all the registries with the information on offsetting provided by the MADS. I found that, although all the projects reported in the cancellation database match consistently with the projects reported in the offset database, the number of credits that the MADS reported as cancelled to avoid carbon tax causation is higher. In fact, the total amount of credits reported as used for non-causation of carbon tax is 10.16 million more than the credits cancelled in the Colombian carbon market during the same period, as detailed in Table 15.

Table 15. Carbon credits cancelled vs. carbon credits used to offset under the offsetting mechanism

Project classification by source/sink	**Cancellations 2017 - 2022**	**Offsets database MADS***	**Credit purchase for other purposes (MADS database)**
	Millions of tonnes of CO_2	Millions of tonnes of CO_2	Millions of tonnes of CO_2
1A. Energy - Hydropower	0.42	0.51	-0.09
1A. Energy - Hydropower	17.20	20.90	-3.72
1A. Energy - Industrial processes	0.19	0.08	0.11
1A. Energy - Petroleum refining	0.70	4.31	-3.61
1A. Energy - Solar power	0.00	0.00	0.00
1A. Energy - Transport	0.23	0.30	-0.07
1A. Energy - Wind power	0.01	0.00	0.01
1B. Energy - Fugitive emissions from fossil fuels	0.03	0.09	-0.06
2. Industrial processes	0.33	0.47	-0.14
5. Land-use change & forestry	27.26	32.65	-5.39
5. Land-use change & forestry - REDD+	49.10	46.47	2.63
6. Waste	3.50	3.20	0.30
No information**	0.00	0.12	-0.12
Total	**98.95**	**109.11***	**-10.16**

** Total Colombian carbon credits used to offset under the offsetting mechanism. I excluded 5.43 million foreign credits used in 2017 in the transition period.*

*** A series of offsets reported in the MADS database that does not contain information about the project where the credits were cancelled.*

Note: The table compares the number of carbon credits cancelled vs. the number of carbon credits used to offset under the offsetting mechanism. The last column results from subtracting the total offset from total cancellations. I obtained the data by consulting all the carbon credit registries available, as described in section 3.3.

This result is controversial since carbon credits used for offsetting to avoid carbon tax causation should be generated within the Colombian national territory (with exception in 2017 when foreign credits were accepted, as described in section 4.3), and all the projects reported in the MADS database are registered in the cancellation database. I double-checked my results using the offsetting data in the newsletter published by the MADS (2023a), which only contains the number of credits used for the offsetting mechanism yearly. The result once again shows inconsistencies between domestic carbon credit cancellations and between the MADS database and MADS newsletter, as depicted in Table 16.

Table 16. Annual cancellation - offset MADS database vs offset MADS newsletter

Year	**Cancellations 2017 - 2022**	**Offsets database MADS***	**Offsets newsletter MADS**	**Credit purchase for other purposes (newsletter)**
	Millions of tonnes of CO_2	Millions of tonnes of CO_2	Millions of tonnes of CO_2	Millions of tonnes of CO_2
2017	2.44	7.71	7.71	-5.26
2018	13.68	11.91	11.91	1.77
2019	13.95	15.64	14.94	-0.99
2020	14.44	13.40	10.12	4.32
2021	21.99	32.41	23.42	-1.43
2022	32.44	33.46	20.76	11.68
Total	**98.95**	**114.53***	**88.87**	**10.08**

** Total Colombian carbon credits used to offset under the offsetting mechanism. To make the MADS database and newsletter comparable, I included 5.43 million foreign credits used in 2017 in the transition period.*

Note: The table compares the database provided by the MADS vs. the newsletter published by MADS (2023a). *The last column results from subtracting the total offset reported in the newsletter from total carbon credit cancellations. I obtained the data by consulting all the carbon credit registries available, as described in section 3.3.*

The findings suggest that the control necessary to enforce the offsetting mechanism is insufficient, leaving room for double counting and, consequently, tax evasion. The lack of controls for the offsetting mechanism was previously discussed in section 4.3, where the failure in the implementation of RENARE was highlighted. RENARE is intended to collect all CO_2 emission removal and reduction data in Colombia from a fragmented market with at least 7 crediting programs (as described in Figure 15). Despite the expectation that RENARE would become operational in September 2018, its current status remains uncertain and no interim tools have been implemented to ensure the accounting of carbon credits. It is unclear whether it is operational for government institutions, while also remaining inaccessible to stakeholders and the general public.

8 Discussion and conclusions

8.1 The effectiveness of the Colombian carbon tax

Given the lack of research about the efficiency of carbon taxes outside the European context and the crucial role that this policy tool promises to play in curbing emissions to achieve Paris Agreement goals, accurately estimating the effectiveness of carbon taxes is important to support government decisions. There are several benefits to employing the synthetic control method for assessing the environmental impacts of carbon taxation. Firstly, this method utilises real-world data on CO_2 emissions after the implementation of the tax, eliminating the need for predictive simulations to estimate emission changes such as using price elasticity to estimate tax impact (Andersson, 2019).

My results from the synthetic control analysis demonstrated the causal relationship between the implementation of the Colombian carbon tax and the reduction of domestic CO_2 emissions in the targeted sector (1A energy source), which comprises all emissions produced by the combustion of fossil fuels. I estimated that, between 2017 and 2022, the Colombian carbon tax led to a reduction of 7% in the country's emissions from fossil fuel consumption compared to Synthetic Colombia, amounting to 77.4 million tonnes of CO_2 emissions.

However, it is important to mention that, ideally, in the performance of synthetic control, a wide number of key predictors should be used in order to represent the structural processes that stir the behaviour of the dependent variable (covariates). Unfortunately, data available for potential drivers of CO_2 emissions, such as energy use, urbanisation, or industrialisation, is limited or incomplete for countries in the Americas. Due to this limitation of data, I chose to use only GDP per capita as a key predictor, meaning that 85% of emission behaviour is explained, ignoring other structural processes that might influence countries' emissions.

Despite this limitation, the emission path of synthetic Colombia is highly similar to that of actual Colombia in the pretreatment period (MSPE 0.01), meaning that it is possible to conclude that both units are similar enough to estimate the effect of the carbon tax after its implementation. The placebo 'in-place' test produced a p-value of 0.06, representing the smallest possible p-value given my sample size, while the robustness tests confirmed that the results are robust to the exclusion of any particular country from the sample.

It is important to note that this result takes into account the effect of carbon pricing policies (carbon taxes and cap-and-trade). However, other climate policy effects implemented in the donor pool countries may have been ignored.

8.2 Environmental integrity of the carbon market

Carbon crediting markets promises to be a flexible and cost-effective market-based approach to reduce emissions (Lang et al., 2019). The objective of the Colombian government, when designing the carbon tax in conjunction with the offsetting mechanism, was precisely that: while the carbon tax makes economic activities based on fossil fuels more expensive each year, the offsetting mechanism provides the private sector with a tool to facilitate the transition to low-carbon alternatives, especially in situations where cleaner technologies are not yet developed or are more expensive than conventional fossil fuel-based ones (MADS, 2023b).

However, as observed in the results presented in sections 6 and 7, the Colombian offsetting mechanism faces similar challenges to those discussed in international arenas: ensuring carbon credit quality and avoiding double counting.

As discussed in section 2.3, ensuring environmental integrity in carbon markets relies mainly on key factors such as evaluating additionality, permanence, and avoiding double counting. These aspects have been primarily emphasised in projects associated with land-use change and forestry, as well as large-scale renewable energy projects (Espejo et al., 2020). Together, these types of credits accounted for 90.4% of the supply in the Colombian carbon crediting market, as detailed in Table 10.

8.2.1 Land-use change & forestry

Guizar-Coutiño et al. (2022) offered a slightly optimistic scenario when discussing additionality for land-use change and forestry, but as demonstrated by West et al. (2023), the additionality and credible baselines of projects are questionable. The divergence between the findings of West et al. (2023) and Guizar-Coutiño et al. (2022) relies on differences in their methodological approaches, study time frames, and the resolution of satellite data used.

While some sources such as Probst et al. (2023) and the journal The Guardian (Greenfield, 2023), suggest that both articles conclude that forest protection was less effective than Verra recorded, Guizar-Coutiño et al. (2022) acknowledge the causal relationship between the introduction of REDD+ projects and reduced deforestation rates in most cases. However, their analysis does not specifically assess the reduction claims made by the Verra projects. In fact, further assessments are needed to reconfirm the exact amount of Verra-certified emission reductions that have been overestimated, since the work of West et al. (2023) may have ignored a number of key predictors that influence deforestation in the areas studied and likely produced less accurate counterfactual areas for determining baselines.

Although not evaluated in this research, permanence is a significant concern associated with land-use change and forestry credits due to the short time scale and duration of conservation projects, potential changes in land use, policy reversals, and vulnerability to natural disturbances (Espejo et al., 2020). To address this issue, offset projects often incorporate buffer reserves, which are credits withheld and not sold to mitigate non-permanent risks. While there are no specific studies assessing the effectiveness of this measure in the Colombian carbon crediting market, existing research suggests that these reserves are often insufficient, particularly in the face of increasing forest risks such as wildfires. For example, (Badgley et al., 2022) found that buffer reserves in California's cap-and-trade forestry projects were nearly depleted after the first decade, despite the need for protection against wildfire risks over the subsequent 100 years.

8.2.2 Energy – Hydropower

Hydropower is recognized for its ability to generate electricity with low GHG emissions, while also providing additional benefits such as flood control and irrigation. Thus, hydropower projects play a crucial role in reducing CO_2 emissions by generating electricity through renewable means. However, large hydroelectric projects are often considered non-additional, and assessing their additionality is challenging due to their status as a conventional technology built extensively worldwide without carbon credits (Haya & Parekh, 2011). Moreover, in Colombia in 2013, hydropower accounted for more than 73% of total electricity generation. As a result, the financial incentives for building large hydropower projects might outweigh the income generated from selling carbon credits, and the technology is quite conventional.

In this context, assessments using financial investment, barrier, and market penetration approaches for large hydropower projects should theoretically negate the issuance of carbon credits. However, these assessments have consistently yielded positive results in terms of additionality, demonstrating flaws in the evaluation process. The dominance of large hydropower projects in the Colombian carbon credit market, particularly those that were in operation prior to the carbon tax but issued carbon credits after the implementation of the carbon tax, raises questions about the integrity of these credits and, consequently, the integrity of the entire Colombian carbon crediting market.

8.2.3 Energy - Petroleum refining and heat power cases.

In the two projects claiming CO_2 reduction in the 'petroleum refining' sector and the one in the 'heat power' sector, emission reduction and avoidance are attributed to process optimisation aimed at reducing fossil fuel consumption. However, despite these efforts, dependence on fossil fuel use persists in all three processes where these projects were implemented, with no new non-conventional technologies being employed. This raises questions about the long-term sustainability and additionality of the market penetration approach.

Furthermore, the economic activities where the projects were implemented are subject to the carbon tax, indicating that the tax may influence the decision to implement emission reduction projects (almost in the two projects implemented after 2017). This potential lack of additionality, combined with the ambiguity between the effects of the carbon tax and the offsetting mechanism, calls into question the integrity of the offsetting mechanism and the credibility of the carbon credits issued.

8.2.4 Double counting

A major risk associated with the offset mechanism is double counting. The Colombian carbon crediting landscape is highly fragmented, with seven crediting programmes operating independently. This fragmentation has led to carbon credit accounting being scattered across different registries that are difficult to compare and unify. As a result, tracking all offsets is becoming increasingly complex.

Unfortunately, despite the design of the offsetting mechanism, including controls through the implementation of the RENARE, a tool intended to compile all emission reduction and avoidance initiatives in the country, Colombia has failed to implement it.

My findings reveal that the lack of effective controls has facilitated tax avoidance, with approximately 10.16 million tons of CO_2 being double counted through the implementation of the offsetting mechanism. This has resulted in a potential reduction in tax revenue of around 208.280 million Colombian pesos[9] (approximately €44,164,920[10]), accounting for 7.5% of the total tax surplus perceived from 2017 to 2022.

Furthermore, tax evasion could decrease the effectiveness of the carbon tax and undermine the integrity of the Colombian carbon crediting market.

8.3 The overall effect of the offsetting mechanism

While the implementation of the offsetting mechanism led to a 92% increase in the supply of carbon credits in the Colombian carbon crediting market, representing 152.01 million tonnes of CO_2, the environmental integrity in terms of additionality, permanence, and avoidance of double-counting for most of the credits is highly questionable, as already discussed in the previous sections. This raises concerns about their validity and the need for further verification before directly attributing these reductions to the offsetting mechanism.

Moreover, the offsetting mechanism results in a reduction in the tax signal, which theoretically could be offset by emissions reductions reallocated in sectors not targeted by the carbon tax. However, the

[9] Using the price of a tonne of CO_2-eq established in 2022 of 20.500 Colombian pesos

[10] This value is calculated by applying the average exchange rate in 2022 of $4,715.96 per euro.

effectiveness of this compensation mechanism is diminished when the integrity of the carbon market is not ensured. This risk was already identified by Wang-Helmreich et al. (2019).

Finally, my findings revealed that the primary demand for carbon credits stems from fossil fuel distributors. This poses a challenge to the assumption that offsetting reallocates economic resources to where emissions reduction is most cost-effective. Since distributors lack direct control over the production processes that consume fossil fuels, their participation in offsetting may primarily reduce the price signal for the final consumer rather than effectively reducing emissions. Additionally, it may lead to profits from the price difference between carbon credits and the carbon tax. Future research might focus on studying this phenomenon adopting quantitative methodologies.

8.4 Final reflection

To conclude, this research has brought to light two main findings, each suggesting a contrasting lesson from the Colombian case. On one hand, results from the synthetic control analysis indicate that the overall policy was effective in reducing national emissions by 7%, and results from the descriptive analysis suggest that the introduction of the offsetting mechanism led to an increase of 92% in domestic carbon credit issuances. On the other hand, the descriptive analysis of the environmental integrity sheds a slightly less optimistic light on the policy, suggesting that the main necessary criteria for the offsetting mechanism to be efficient were not entirely fulfilled.

Acknowledging this lack of environmental integrity of carbon credits and the first results concerning the overall efficacy of the policy are therefore even more remarkable, noting that despite the lack of environmental integrity, the policy reached a decrease in emissions of 77.4 million tonnes of CO_2. This suggests, in particular, that the reduction could be even stronger if the environmental integrity of the credits could be enforced. To rich such as environmental integrity implementing the RENARE registry -as required by the law- is essential, but also set a series of rules to define which removal and reduction initiatives can be used to offset mechanism and which economic activities can accesses to the offset mechanism.

From the RENARE registry, the minimum requirements needed to achieve such as environmental integrative are already defined in the law (MADS, 2018):

- Register all CO_2 emissions avoidance and reduction initiatives in Colombia and provide information related to the status of the initiative in all phases of the project (proposed, implemented, completed).
- In a fragmented carbon credit market, contribute to the standardisation of information related to CO_2 emission avoidance and reduction initiatives.
- Maintain a record and accountability of all carbon credits issued and cancelled in the carbon credit market and the purpose of the cancellation (for non-carbon tax or other voluntary purposes). In this regard, ensure the unique identification of each carbon credit to avoid double counting.
- Maintain public information for consultation by government institutions, stakeholders and the general public.

Furthermore, in order to define which removal and reduction initiatives can be used for the offset mechanism, it is necessary to exclude initiatives that directly overlap with the sectors targeted by the carbon tax but also to exclude emission avoidance and reduction initiatives that do not comply with the principles of permanence or additionality. In addition, limiting access to the offset mechanism to economic activities that directly consume fossil fuels and are in a position to decide to adopt low-carbon technologies, rather than fossil fuel distributors, thus ensuring that if the price of the fiscal signal is reduced through offsetting, it is because economic resources are reallocated to where emission reductions are most cost-effective, rather than by commercial decision.

Finally, one aspect that is outside the scope of this research but which is of great importance in carbon markets is the price of carbon credits. The price of the carbon tax undoubtedly caps the price of carbon credits, as the demand for credits is dominated by the desire to offset to reduce the carbon tax burden. Is the price of carbon credits high enough to incentivise the development of CO_2 emission removal or reduction initiatives capable of producing quality carbon credits?. Or, does carbon taxes in conjunction with offsetting mechanisms delaying the development of domestic high integrity carbon crediting market?

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