Colombia's Carbon Tax and Offsetting Mechanism: A Synthetic Control Evaluation of Emissions and Deforestation

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Title of Internship Report

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Abstract

In 2017, Colombia introduced a carbon tax with an offsetting mechanism that initially allowed entities to cover up to 100 percent of obligations with certified carbon credits, reduced to 50 percent in 2023. Despite being the first hybrid carbon pricing policy in Latin America, its impacts have yet to be thoroughly evaluated. To address this gap, this study applies the Synthetic Control Method (SCM) to assess the effects of Colombia's hybrid carbon tax from 2017 to 2023. The results show that CO_2 emissions from fossil fuels and industrial processes, excluding land-use change, initially declined but later rebounded, ultimately surpassing the synthetic counterpart by an average of −0.086 metric tons per capita. CO_2 emissions from oil, more directly targeted by the tax, saw only a short-lived and insignificant reduction of −0.064 metric tons per capita. Tree cover loss also remained slightly above that of the synthetic counterpart, averaging 0.054 percentage points higher. Two main factors help explain the policy's limited effectiveness. First, the relatively low tax rate and broad exemptions, especially the exclusion of coal, likely weakened the price signal, a situation worsened by increased fossil fuel subsidies during COVID-19 and falling carbon credit prices after 2021. Second, systemic shortcomings in REDD+ projects, including limited institutional capacity, misaligned incentives, weak enforcement, and low local engagement, likely further reduced their credibility and impact. These findings suggest that Colombia's hybrid carbon pricing policy has not yet reached its full mitigation potential, underscoring the need for ongoing monitoring and targeted reforms.

Keywords: Colombia, Carbon tax, Offsetting mechanism, Synthetic Control Method (SCM), Deforestation, CO_2 Emissions

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List of Abbreviations

ADB	Asian Development Bank
aSSIST	Seoul School of Integrated Sciences & Technologies
DID	Difference-in-Differences
ETS	Emissions Trading System
FPIC	Free, Prior, and Informed Consent
FSI	Fragile States Index
GHG	Greenhouse Gas
IPS	Industrial Policy Studies
MADS	Ministry of Environment and Sustainable Development of Colombia
MRV	Monitoring, Reporting, and Verification
MSPE	Mean Squared Prediction Error
NDCs	Nationally Determined Contributions
REDD	Reducing Emissions from Deforestation and Forest Degradation
RENARE	National Emission Reduction Registry (Registro Nacional de Reducción de Emisiones de Gases de Efecto Invernadero)
SCM	Synthetic Control Method
SDGs	Sustainable Development Goals
UNITAR	United Nations Institute for Training and Research
VVBs	Validation and Verification Bodies

I. Introduction

The Integovermental Panel on Climate Change (2023) projects that based on current greenhouse gas (GHG) emission trajectories aligned with Nationally Determined Contributions (NDCs) submitted prior to COP26, the world is likely to exceed 1.5°C of warming during the 21st century. This trajectory jeopardizes the Paris Agreement's goal of limiting global warming to well below 2°C, unless immediate and far-reaching mitigation efforts are undertaken. Reinforcing this urgency, the World Meteorological Organization (WMO) confirmed that 2024 was the warmest year on record, with global average temperatures reaching 1.55°C above pre-industrial levels (WMO, 2024). While a single year exceeding 1.5°C does not signify the failure of the Paris Agreement, it can still be considered a critical warning of intensifying climate risks.

To address the accelerating pace of global warming, countries have adopted various policies. Among these, carbon pricing has gained increasing recognition as a central policy tool to mobilize finance and secure development outcomes, with 28% of global greenhouse gas emissions and two-thirds of global GDP now covered by such mechanisms (World Bank, 2025). Countries such as Sweden and Finland implemented carbon taxes as early as the 1990s, and countries like Japan and Singapore introduced carbon taxes in the 2010s, while others, including Korea and New Zealand, have more recently adopted Emissions Trading Systems (ETS). There are also multiple experiences with carbon taxes and emission credit markets in Latin America; compared to Europe, these have only been implemented since the 2010s. For instance, Chile introduced a carbon tax in 2017, but began formalizing an offsetting mechanism in 2023. Argentina adopted a carbon tax in 2018 without any offset mechanism (IMF, 2023; Climate Action Tracker, 2021). In contrast, Colombia launched its carbon tax in 2017 with a distinctive hybrid model that allowed liable entities to offset up to 100% of their carbon tax liability through certified emission reduction projects until 2022, after which the allowance was reduced to 50% in 2023 (Argus Media, 2025b). Between 2017 and 2023, it remained the only country in the region to operationalize such a hybrid approach, according to the World Bank's Carbon Pricing Dashboard, whereas systematic empirical assessments of its effectiveness remain limited, particularly with respect to its impact on emission reductions and deforestation dynamics.

Against this backdrop, and amid growing global attention on Latin America—particularly following COP16 on biodiversity in Colombia and COP30 in Belém, Brazil—this study evaluates the effectiveness of Colombia's hybrid carbon tax and offsetting mechanism. Assuming the hypothesis that this policy affects both carbon emissions and deforestation, the study applies the Synthetic Control Method (SCM) to identify causal impacts, focusing on three core research questions: *the extent to which the hybrid carbon tax has reduced (a) CO_2 emissions from fossil fuels and industrial processes, excluding land-use change*; *its specific impact on (b) CO_2 emissions from oil*; and *the influence of the associated offsetting mechanism on (c) Tree*

Cover Loss. Based on the empirical findings, the study also explores the underlying mechanisms behind the observed effects and offers policy recommendations for enhancing the design and effectiveness of hybrid carbon pricing instruments in developing contexts.

To achieve these objectives, the paper proceeds as follows. Section 2 introduces the general concepts of carbon pricing and credit mechanisms. Building on this, Section 3 provides an overview of Colombia's carbon pricing framework, including its institutional design and implementation process, and reviews the existing literature on carbon pricing and hybrid mechanisms, situating Colombia's experience within broader global and regional contexts. Following this conceptual groundwork, Section 4 outlines the methodological strategy and data sources. Section 5 then presents the results and robustness checks, while Section 6 explores the underlying mechanisms and discusses their policy implications. Finally, Section 7 concludes with key findings and recommendations for future research.

II. Climate Policy Instruments

2.1 Carbon Pricing Mechanism: Taxation and ETS

Among the various climate policy instruments, carbon taxes and emissions trading systems (ETS), collectively referred to as carbon pricing mechanisms, have played a crucial role in mobilizing finance and achieving development outcomes by assigning a cost to carbon emissions (World Bank, 2025). From an economic perspective, this approach is intentionally designed to internalize external effects that are not adequately reflected in market prices, thereby discouraging emissions through higher costs using market mechanisms rather than outright bans. Compared to the early 1990s, when only a few developed countries such as Sweden had implemented them, the number of jurisdictions adopting such mechanisms has grown substantially. As of 2025, 80 carbon pricing instruments were in operation, with an additional three scheduled for implementation (World Bank, 2025). Notably, the launch of China's national ETS in 2021 significantly expanded global coverage, with carbon pricing mechanisms collectively covering approximately 28% of GHG emissions (World Bank, 2023)

More specifically, a carbon tax constitutes a policy instrument that directly levies a fixed fee per ton of CO_2 emitted, typically applied to fossil fuel producers or users. A carbon tax is relatively simple to implement, as it can be integrated into existing tax systems, in contrast to the higher complexity of an ETS, which may require new institutional arrangements (UNFCCC, 2023). Additionally, a carbon tax can be applied across a broad range of sectors, including those that are difficult to regulate through an ETS, which primarily targets high-emission facilities in the power and industrial sectors (Black & Zhunussova, 2022; UNFCCC, 2023). However, it does not guarantee a specific level of emission reductions, as companies may choose to pay the tax rather than reduce their carbon output. With these characteristics, the real-world outcomes of carbon taxes have been mixed from limited to significant effects. For instance, findings from British Columbia, where a carbon tax was implemented in 2008, suggest that reductions in CO_2 emissions and gasoline consumption were only observed in the short term (Arcila & Baker, 2022). However, other evidence from British Columbia indicates that the tax also led to a notable reduction in natural gas use, particularly in the residential sector (Xiang & Lawley, 2019). Regarding Australia's carbon tax, due to its rapid and steep price increases, it faced strong public opposition and was abolished after only two years, transitioning to an ETS one year earlier than initially planned (Putri & Hutapea, 2024). By contrast, Sweden's carbon tax led to a significant reduction in transport-related CO_2 emissions between 1990 and 2005 (Andersson, 2019).

In contrast, ETS sets a limit (cap) on the total amount of GHG emissions allowed for certain industries. Companies are allocated or can purchase emission allowances, which they can trade with one another based on their actual emissions. If a company emits less than its allowance, it can sell the surplus; if it emits more, it must buy additional allowances. The main advantage of an ETS is that it provides great certainty about the total emissions level, despite potential leakage issues, since the cap is set by the government, ensuring that environmental goals are met (World Bank, 2021). However, since the price of allowances is determined by the market, the intended effect could not materialize as expected (Black & Zhunussova, 2022; Öztürk, 2024). If market prices are set too low, for example due to weak demand, companies may lack sufficient incentives to reduce emissions and instead opt to purchase allowances, leading to outcomes similar to those observed under low-rate carbon taxes. Furthermore, compared to a tax system, an ETS requires substantial administrative capacity. This includes complex tasks such as determining the initial allocation of allowances, selecting distribution methods (e.g. auctions or free allocation), and regularly adjusting the cap to ensure market effectiveness (Black & Zhunussova, 2022; UNFCCC, 2023). With these characteristics, the effects of the ETS have been mixed, similar to those of the carbon tax. For example, the Republic of Korea has operated an ETS since 2015. However, despite a steady increase in trading volume, a disproportionately high share of allowances has been allocated for free, and with the reduction in GHG emissions during the COVID-19 period, allowance prices have fallen since 2019, thereby weakening the system's effectiveness in driving low-carbon investment (Kim et al., 2025). On the other hand, the ETS implemented in Europe since 2005—the first multinational GHG cap-and-trade system—currently covers 30 countries (27 EU member states and three additional countries: Iceland, Liechtenstein, and Norway). It has been associated with a reduction in carbon emissions of around 10% between 2005 and 2012, while having no significant negative impact on profits and employment and even leading to increases in regulated firms' revenues and fixed assets (Dechezleprêtre et al., 2023).

To summarize, both carbon taxes and ETS can serve as effective tools for reducing CO_2 emissions when properly designed to influence behavior and market dynamics. An effective carbon tax should establish a sufficiently high and predictable price signal to encourage emission reductions, while enhancing social acceptability and equity through complementary mechanisms that address the disproportionate burden on vulnerable groups. By contrast, an ETS should establish robust monitoring, reporting, and verification (MRV) systems, as well as regular adjustments to remain effective. Additionally, the gradual phase-out of free allowances is essential to sustain market credibility. However, as illustrated by the country cases, the effectiveness of both instruments further depends on their specific policy design, implementation, and broader socioeconomic context, underscoring the need to evaluate their outcomes on a country-by-country basis.

2.2 Carbon Crediting Mechanisms: REDD+

To complement these carbon pricing instruments, carbon crediting mechanisms have also been considered to be adopted. These frameworks facilitate the creation of tradable credits representing verified emissions reductions or removals, derived from voluntarily implemented mitigation activities (World Bank, 2021). Such activities span a wide spectrum, from small-scale individual projects to expansive programmatic or sectoral undertakings across diverse technical and geographic domains. Credits can be issued under domestic schemes, where national authorities define eligibility and methodological standards, or through international platforms such as the Article 6.4 mechanism established under the Paris Agreement (World Bank, 2021).

One of the most widely recognized approaches to carbon crediting is REDD+, which stands for "Reducing Emissions from Deforestation and Forest Degradation," with the "+" referring to additional forest-related activities such as sustainable forest management, conservation, and the enhancement of forest carbon stocks (UNFCCC, n.d.). To achieve forest conservation and sustainable land use, REDD+ initiatives commonly incorporate interventions such as advanced forest monitoring systems, stricter enforcement, the promotion of sustainable land-use practices, and the inclusion of local and Indigenous communities in forest governance (West et al., 2023). These efforts not only aim to mitigate deforestation and degradation but also generate co-benefits, including biodiversity preservation and improved local livelihoods.

Emission reductions under REDD+ are generally quantified using a baseline-and-credit approach. This methodology compares observed forest cover in a project area with a counterfactual baseline scenario that estimates the deforestation or degradation that would have occurred in the absence of REDD+ interventions (ADB, 2024). The resulting difference, representing avoided emissions or preserved carbon stocks, is subsequently verified by accredited third parties such as Verra, certified, and issued as tradable carbon credits (ADB, 2024). These credits can be used in both compliance markets (e.g., to meet obligations under carbon taxes or emissions trading systems) and voluntary markets (e.g., by companies aiming to achieve net-zero commitments) (World Bank, 2021).

The role of REDD+ within the Land Use, Land-Use Change, and Forestry (LULUCF) sector has gained increasing recognition as a key component of national mitigation strategies under the updated NDC 2.0 and NDC 3.0 frameworks (UN-REDD Programme, 2022). Of the many countries adopting such approaches, those with extensive forest cover—such as Bhutan and Lao PDR—have shown particular interest in integrating REDD+ into their national development plans to promote sustainable economic growth consistent with their ecological conditions. As a result, as of 2021, REDD+ projects accounted for approximately two-thirds of the 227.7 million carbon credits traded in carbon markets from the land-use sector (excluding agriculture), with an estimated market value of USD 1.3 billion (West et al., 2023).

Regarding the effects of REDD+, given the complex structure of the projects, the outcomes have been mixed and remain controversial. According to West et al. (2023), an evaluation of 26 REDD+ project sites across six countries between the 2000s and 2010s found that overall reductions in deforestation were limited when compared to ex post counterfactual scenarios. These findings underscore concerns about the credibility of baseline assumptions and the risk of over-crediting emissions reductions, highlighting the need for rigorous monitoring systems, transparent crediting methodologies, and stronger alignment with national policy frameworks. Furthermore, given the long-term nature of REDD+ projects, not all planned areas have ultimately been reforested. For instance, the Guangxi project in China was designed as a 30-year initiative to restore 4,000 ha of degraded land through multiple-use forestry. However, only 55% of the project's land had been successfully planted with trees, as some areas were too degraded or too expensive to reforest, while other areas were diverted to alternative uses due to higher opportunity costs (van Kooten, 2017; Gong et al., 2010). Nonetheless, these shortcomings do not constitute a complete failure in all respects. As Andrews and Mulder (2024) argue, the REDD+ initiative in Pemba, Zanzibar, ultimately failed to produce carbon credits and deliver on its original objectives. At the same time, however, exposure to REDD+ was associated with fewer protest bids and higher levels of expected future participation. Thus, it is important not only to focus on numerical outcomes or Key Performance Indicators (KPIs), but also to contextualize the results through qualitative analysis for a comprehensive understanding, while considering the long-term behavioral changes induced by REDD+.

III. Colombian Carbon Tax

3.1 Background and Objectives of Carbon Tax in Colombia

Colombia introduced its carbon tax through Law 1819 in 2016, which was implemented in 2017, making it one of the earliest policies in Latin America. Colombia's carbon tax applies upstream to domestic fossil fuel producers and importers, targeting products such as gasoline, diesel, kerosene, jet fuel, fuel oil, and industrial usage of natural gas for refining hydrocarbons and petrochemicals, and industrial liquefied petroleum gas, while excluding coal and other solid fuels (Giovanni et al., 2022; Baquero et al., 2023; UNDP, 2025). Its primary objective was to address fiscal deficits exacerbated by the 2014 decline in global oil prices, which had a significant impact on Colombia as a major oil producer and exporter, while simultaneously signaling the country's commitment to climate action through the introduction of a carbon tax initially set at USD 5 per ton of CO_2 equivalent, with an annual 1% inflation-adjusted increase, rising to USD 6.89 (UNDP, 2025; Maradan, 2025). This rate is an order of magnitude below that of other developed countries, such as Sweden and Finland, while covering only around 31% of Colombia's total greenhouse gas emissions (OECD, 2024). Nonetheless, as Sandel (2020) expressed, taxation is not only a way of raising revenue; it is also a means of expressing a society's judgment about what counts as a valuable contribution to the common good. In other words, despite its limited coverage, the timing and symbolic importance of Colombia's carbon tax policy reflect the government's commitment to climate action, marking the first carbon pricing mechanism implemented in the Amazon region.

Revenues generated from the tax are allocated to the Colombian Peace Fund (Fondo Colombia en Paz), with designated shares supporting a range of sustainability initiatives. Specifically, 25% of the collected revenue is earmarked for climate adaptation efforts, including coastal erosion control, deforestation monitoring and reduction, watershed conservation, and ecosystem restoration (UNDP, 2025). An additional 5% is directed toward strengthening Colombia's National System of Protected Areas, which encompasses ecologically critical regions such as tropical montane cloud forests, tropical savannahs, humid forests, and Andean ecosystems. The remaining 70% of the funds support post-conflict development programs, aimed at addressing the social and economic challenges in formerly conflict-affected areas (UNDP, 2025). In other words, this policy is designed not only to reduce carbon emissions and generate fiscal income but also to address nature-related challenges and support conflict-related aid.

3.2 Hybrid Design: the Offsetting Mechanism in Colombia

A key distinguishing feature of Colombia's carbon tax regime is its integrated offsetting mechanism. Introduced under Decree 926 of 2017, this provision allowed liable entities—primarily fossil fuel importers and sellers—to fulfill their tax obligations through the use of domestic carbon offsets. Specifically, the hybrid design is intended to link the carbon tax with carbon markets to mobilize private finance for climate action by providing firms with the alternative of investing in carbon crediting projects instead of paying solely through taxes (UNDP, 2025). As intended by this hybrid method, Colombia's carbon market has grown significantly. Between 2017 and 2024, 167 mitigation projects were approved under this offsetting mechanism, enabling companies to meet their tax liabilities through credits, with a total of 112 million tons of CO_2 equivalent offset during this period (Argus Media, 2025a; Asocarbono, 2025). Notably, as of 2023, about 36% of all carbon credits issued in Colombia were cancelled to comply with carbon tax obligations, particularly by fossil fuel distributors such as Primax Colombia (Maphanga, 2023; Dufrasne, 2021). Initially, up to 100% of the carbon tax liability could be offset through certified emission reduction projects, but this allowance was reduced to 50% in 2023. This adjustment may reduce the positive spillover effects of carbon crediting on other emission sources covered by the carbon tax, while it could increase the effective tax burden and boost government green tax revenues amid ongoing fiscal constraints (Wang-Helmreich & Kreibich, 2019; Argus Media, 2025b).

While the credits generated from outside Colombia were allowed during the initial phase until the end of 2017, eligibility has been restricted to carbon credits generated within Colombia since 2018 (Dufrasne, 2021). To safeguard environmental integrity, Decree 926 requires that eligible credits be generated within the previous five years and certified under recognized standards accredited either by Colombia's National Accreditation Body or a member of the International Accreditation Forum (UNDP, 2025). Furthermore, the Ministry of Environment and Sustainable Development (MADS) issued Resolution 1447 in 2018, which established comprehensive requirements for project registration, MRV, as well as accounting procedures (Dufrasne, 2021). Under this framework, the National Emission Reduction Registry (RENARE) was established as the official online registry to centralize information on GHG mitigation initiatives and serve as a public monitoring and reporting tool for all mitigation activities, including REDD+ projects (IEA, 2018; Franco, 2019; Global Financial Integrity et al., 2025). However, RENARE did not become operational until late 2020 and has since faced repeated suspensions, which have undermined transparency and restricted access to reliable information. Even when functional, the platform has largely operated as a passive repository without strong verification mechanisms, leaving the responsibility for data accuracy entirely to project developers. This regulatory gap has enabled potential over-crediting and raised concerns over weak enforcement by the ministry (Dufrasne, 2021).

Given the structural linkage of the carbon tax with the offsetting mechanism, which has mobilized significant private-sector finance for crediting projects while simultaneously reducing potential tax revenues and still requires improvements in monitoring and verification, evaluating the effectiveness of Colombia's carbon tax solely on the basis of emission-based reductions may not be sufficient for a comprehensive assessment and may lead to misleading conclusions. In other words, it is also necessary to examine carbon credit markets, particularly REDD+ alongside carbon emissions, as this would provide a more comprehensive and reliable measure of the policy's overall effectiveness.

3.3. Assessing Policy Outcomes and Risks in Colombia

As highlighted earlier, Colombia's carbon tax operates as a complex mechanism that integrates both taxation and offsetting components. To analyze its comprehensive outcomes, it is essential to review how existing studies have assessed the policy's effects on carbon emissions and deforestation, as well as its limitations.

Putri and Hutapea (2024), using a comparative qualitative approach with data collection methods involving documentation and literature review, argue that the Colombian policy aims to reduce the consumption of fossil fuels by users of these energy sources, functioning similarly to taxes on plastic bags that seek to change consumer behavior. However, given the limited availability of viable alternatives, technologies, and substitute energy sources, achieving this transition requires substantial investments, making it difficult to realize in practice. Moreover, the tax excludes other significant sources of GHG emissions, such as landfills, which limits its overall effectiveness and results in coverage of only about 31 percent of total emissions. Focusing on the offsetting mechanism, Mendieta and Grueso (2024), using a descriptive analytical approach, highlight the progressive nature of Colombia's carbon pricing system, which has attracted significant multinational investment in forest-based projects across regions such as Antioquia, Boyacá, Huila, Nariño, Santander, and Valle del Cauca. These projects, implemented with local communities, generate carbon credits that are verified by third parties and sold to fuel suppliers and importers to meet tax obligations, with Primax being the largest buyer at 5.2 million units in 2019, followed by Terpel, Biomax, and ExxonMobil (Dufrasne, 2021; Bermúdez Liévano, 2021). Wang-Helmreich and Kreibich (2019), drawing on existing literature, examined the potential risks associated with Colombia's domestic offsetting mechanism. They argued that this approach could undermine expected revenues from the carbon tax and raised concerns about environmental integrity due to low-quality offsets. Furthermore, limited institutional capacity within RENARE increases the risk of issuing credits that fail to deliver real climate benefits or forest conservation outcomes (Global Financial Integrity et al., 2025). Aligned with this argument, Dufrasne (2021) highlighted that two large-scale REDD+ projects in Colombia's Amazon region—Mataven and Kaliawiri—used inflated baselines to estimate avoided deforestation. As a result, approximately 21 million additional carbon credits, equivalent to 21 million metric tons of CO_2 (or an equivalent amount of other GHG emissions reduced, sequestered, or avoided), were issued (UNDP, 2022; Dufrasne, 2021). This illustrates the risk that Colombia's offset mechanism may fail to achieve genuine emissions reductions, potentially undermining both the environmental integrity and the fiscal objectives of the carbon tax.

Overall, prior research has highlighted the strengths and limitations of the carbon tax and its offsetting mechanism, while focusing either solely on the offsetting mechanism or on the direct impact of the carbon tax, rather than examining them together in a comprehensive way. To better understand the actual outcomes of Colombia's hybrid carbon pricing framework, this study provides a quantitative assessment of both the carbon tax and the offsetting mechanism in a comprehensive manner by employing qualitative methods to contextualize the findings and their implications.

3.4 Assessing Policy Outcomes and Risks in Other Countries' Carbon Tax

A number of studies have investigated the effectiveness of carbon taxes using quantitative analysis. Among various quantitative methods, the Synthetic Control Method (SCM), initially proposed by Abadie and Gardeazabal (2003), has been adopted to evaluate policy impacts, particularly in carbon tax policies. SCM constructs a counterfactual control group by assigning appropriate weights to untreated units, allowing researchers to compare outcomes with the treated unit and assess the effectiveness of policy interventions. For example, Xiang and Lawley (2019) employed both panel data regression and SCM to estimate the effects of British Columbia's carbon tax, implemented in 2008, on per capita residential natural gas consumption between 1990 and 2014. Their findings indicate that the carbon tax led to a significant reduction in natural gas use, with per capita residential consumption decreasing by approximately 6.9% on average compared to the synthetic counterpart. Arcila and Baker (2022) also analyzed British Columbia's carbon tax by applying SCM to evaluate the long-term effects on CO_2 emissions and gasoline consumption up to 2017, just before the implementation of Canada's federal carbon pricing policy. Their analysis revealed that although CO_2 emissions and gasoline consumption declined in the short term, these trends reversed over time. By the end of the study period, emissions in British Columbia exceeded those of the synthetic counterpart, and employment in the energy sector had declined, suggesting potential structural limitations of the tax policy. These contrasting findings demonstrate that the evaluation of British Columbia's carbon tax can vary substantially depending on the sector and outcome variables examined, underscoring the importance of methodological choices in policy assessment.

In the case of Sweden, one of the earliest adopters of carbon taxation since 1991, Andersson (2019) employed SCM to estimate the impact of the Swedish carbon tax on transport-related CO_2 emissions between 1990 and 2005. The analysis indicated that Sweden's transport emissions declined by approximately 11% annually, on average, relative to its synthetic counterpart, with around 6% of the reduction directly attributable to the carbon tax itself. This finding contrasts with earlier analyses of the Swedish carbon tax, such as Lin and Li (2011), who used a Difference in Difference (DiD) methodology and reported no significant reduction in the growth rate of per capita CO_2 emissions. Andersson argued that these discrepancies stemmed from methodological limitations, such as the use of total CO_2 emissions, which failed to distinguish between "treated" and "untreated" sectors. Aligned with this Swedish carbon tax study, Elbaum (2021) analyzed the effect of the carbon tax in Finland, the first country to introduce a carbon tax in 1990, using SCM to assess the policy's impact on transport-related emissions between 1965 and 2005. The study found that, five years after the intervention, per capita transport-related CO_2 emissions in Finland were nearly 20% lower than those in the synthetic control, although overall per capita CO_2 emissions in Finland continued to rise after the tax implementation, particularly before the 1997 tax rate increase. Together, these findings underscore the critical role of methodological choices and careful consideration of taxed sectors—such as exemptions—in accurately evaluating the effectiveness of carbon taxation.

Bretschger and Grieg (2024) also employed SCM to examine the impact of a fuel tax in the UK—introduced in 1993 with the explicit objective of reducing pollution from road transport—on both transport-related CO_2 emissions and GDP. While the tax studied may not be considered a comprehensive carbon tax, the authors argue that it can function in a similar way and offer indicative insights into the broader effects of carbon pricing policies. Based on this argument, the tax had a substantial and statistically significant impact on transport-sector emissions, reducing CO_2 by approximately 0.352 metric tons per capita on average in the UK, whereas there is no discernible adverse effects on GDP levels or economic growth, reinforcing the argument that environmental taxes can be compatible with sustained economic performance.

Kraynak et al. (2024) analyzed the impact of Australia's national climate policy expansion and the implementation of a short-lived carbon tax on CO_2 emissions between 1980 and 2018, with particular focus on the period from 2009 to 2018, when major climate policies were introduced and expanded. The term "short-lived carbon tax" refers to the carbon tax introduced in 2012, which was repealed just a year later in 2013 due to strong public opposition, leading to the implementation of an ETS a year earlier than originally planned (Putri & Hutapea, 2024). To conduct the analysis, the study applied a demeaned SCM by subtracting the country-specific pre-treatment mean from the outcome variable, which removes level differences and improves matching quality. According to the study, the combination of expanded climate policies and the temporary carbon tax in Australia led to a 7% reduction in CO_2 emissions per capita from 2009 to 2018, estimated at 1.37 metric tons per capita annually. However, the study also notes that the policy mix did not reduce the production of Australian coal and may have even increased its exports, suggesting potential risks of emissions leakage and political costs associated with the policy.

Overall, the reviewed literature across a range of policy environments shows that carbon taxes have been widely analyzed using SCM, which provides a robust framework for constructing counterfactuals and inferring plausible causal effects in settings where randomized experimentation is not feasible. However, the outcomes of SCM analyses may differ from those obtained using other methodologies—or even when applying the same methodology—depending on the specific outcome sector, selection of control units, and predictor variables. This underscores the importance of careful contextual judgment in both model design and interpretation.

IV. Methodologies

4.1 Synthetic Control Methods

Aligned with previous research on carbon taxation (e.g., Andersson, 2019), this study examines the impact of Colombia's carbon tax and additionally extends the analysis by evaluating its offsetting mechanism, using SCM. Specifically, based on the hypothesis that this hybrid carbon offsetting mechanism would impact reductions in carbon emissions and deforestation, this study estimates the effect of the carbon tax on *(a) CO_2 emissions from fossil fuels and industrial processes, excluding land-use change* (hereafter, CO_2 emissions excluding Land-Use), its targeted impact on *(b) CO_2 emissions from oil*, and the effect of the associated offsetting mechanism on (c) *Tree Cover Loss (%).*

The decision to apply SCM is grounded in both contextual and methodological considerations. Similar to the difference-in-differences (DiD) approach, SCM effectively incorporates pre-treatment characteristics. However, the DiD approach requires the strict parallel trends assumption, which is often difficult to verify in practice. In contrast, SCM does not rely on this assumption and accommodates time-varying unobserved confounders by weighting the control group instead of assigning equal weights to all units, thus producing a more comparable synthetic counterpart (Andersson, 2019). By constructing such counterparts that replicate pre-policy trends, SCM further enables researchers to assess how outcomes diverge after implementation and to visualize the dynamic effects of a policy over time (Abadie, 2020). However, as demonstrated in previous sections, the method can yield divergent outcomes depending on the selection of predictors, donor pools, or policy scope (e.g., Xiang & Lawley, 2019; Arcila & Baker, 2022). Moreover, some policies, such as fuel taxes in the UK (Bretschger & Grieg, 2024), function similarly to carbon taxes but are not officially classified as such, complicating the construction of appropriate control units. These limitations suggest that, while SCM offers a robust framework for causal inference in quasi-experimental settings, its reliability hinges on the careful selection of predictors and donor pools, consistent policy definitions across units, and rigorous contextual interpretation. Accordingly, the analysis will be supplemented by qualitative insights drawn from the literature in the following sections.

To build a robust synthetic counterpart using SCM, it is essential to exclude countries that implemented a national-level carbon tax between 2000 and 2017 when constructing the donor pool for estimating the counterfactual emissions trajectory. For instance, Chile and Argentina, which introduced carbon taxes in 2017 and 2018, respectively, were excluded from this study. However, as mentioned, this approach may overlook subnational initiatives or other tax systems that are not officially classified as national carbon taxes. In this context, the World Bank database serves as a consistent and internationally recognized source for identifying carbon pricing policies, justifying its use as the primary reference for donor pool construction in this study. At the same time, there remains a potential risk of spillover effects contaminating the donor pool (Aquino et al., 2025). For example, Colombia's first-mover advantage in carbon offset projects may have influenced investment flows and policy responses in neighboring countries, potentially biasing the estimated effects. To mitigate these risks, this study conducts robustness tests in subsequent sections, varying the time periods, geographical donor pools, and model specifications to verify the consistency of results across multiple dimensions.

In terms of donor pool selection, several strategies exist for constructing a donor pool, ranging from province-level units to mixed approaches and purely national-level samples. Since Colombia's carbon tax and its offsetting mechanism were implemented at the national level, the donor pool should be constructed using national-level data to reflect the full scope of the policy. Building on this approach, there are also various strategies for selecting donor units when constructing a synthetic counterfactual. For example, Andersson (2019) created a synthetic Sweden by aggregating 14 OECD countries. However, such an approach would not be suitable for Colombia, which is neither an OECD nor an EU member. Alternatively, Arcila and Baker (2022), who analyze British Columbia's carbon pricing, selected not only Canadian provinces but also nearby U.S. states, prioritizing geographical proximity and economic similarities. Combining these standards—which emphasize economic comparability and regional relevance—this study selects 14 national-level units in South and Central America that have not implemented a carbon tax as the donor pool for Colombia.

4.2 Technical Aspects

For the general setup of the synthetic control, this study considers j+ 1 units, where unit j =1 represents the treated unit. In this case, the treated unit is Colombia, which implemented a carbon tax policy with offsetting mechanism in 2017. It is compared against a set of control regions j = 2, 3, …, j +1 , which were not subject to any similar policy changes. All countries are observed for T time periods; in this study, T = 23, denoted as t = 1, 2, …, T. To construct a reliable synthetic counterfactual and evaluate the policy's effect, it is essential to have a sufficient pre-treatment period (t = 1, 2, …, T_0) and a post-treatment period (t = T_0+ 1, T_0 + 2, …, T).

Synthetic Colombia is created as a convex combination of these control units, represented by a weight vector W = (w_2 , …, w_{J+1})′, where each weight satisfies $0 \leq w_j \leq 1$ and the sum of all weights equals 1. Each choice of W yields a unique synthetic Colombia that replicates the pre-treatment characteristics of the treated unit. Greater weight is assigned to the predictors that demonstrate higher explanatory power for the outcome variable during the pre-intervention period, compared to other candidate predictors included in the donor pool. The relative importance of each predictor is not determined subjectively, but is endogenously chosen through the optimization process within the synthetic control method. While several approaches exist for selecting the diagonal matrix V of predictor weights, this study adopts a data-driven strategy that jointly optimizes both W and V to minimize the mean squared prediction error (MSPE) of the outcome variable over the pre-treatment period. Thus, predictors that contribute more effectively to reproducing the trajectory of the treated unit before the intervention are automatically given greater weights.

4.3 Data

Using this methodological framework, the study employs annual panel data spanning 2001 to 2023. This period provides 16 years of pre-treatment data (2001–2016) and 7 years of post-treatment data (2017–2023), offering a sufficient time horizon to construct a synthetic control and assess short- to medium-term policy impacts.

For donor country selection, among the 12 South American and 7 Central American countries in the region, Belize is excluded due to insufficient data on tree cover loss, while Chile, Argentina, and Uruguay are excluded because they implemented carbon pricing mechanisms during the study period, as indicated by the World Bank's Carbon Pricing Dashboard. Colombia is also excluded as it is the treated unit. This exclusion is necessary to uphold the no-treatment assumption required by SCM, ensuring that the estimated differences in CO_2 emissions and tree cover loss between Colombia and its synthetic counterpart can be more reliably attributed to Colombia's carbon tax policy. Consequently, the final donor pool for synthetic Colombia comprises 14 countries: Bolivia, Brazil, Ecuador, Guyana, Paraguay, Peru, Suriname, Venezuela, Guatemala, Costa Rica, Panama, El Salvador, Honduras, and Nicaragua.

The outcome variables for (a) CO_2 emissions excluding Land-Use and (b) CO_2 emissions from oil are measured in metric tons per capita. The predictor variables used for this analysis include the logarithm of GDP per capita and the urbanization rate (%) from the World Bank, both serving as proxies for economic development and commonly adopted in studies such as Andersson (2019), Elbaum (2021), and Bretschger and Grieg (2024). In addition, the industrial share of GDP (%), oil rents (% of GDP), and fuel exports (% of merchandise exports) from the World Bank are included to capture the structural characteristics of Central and South American economies. These variables are averaged over the 2001–2016 pre-treatment period. Given the few missing data points, this study applies midpoint imputation when a single year is missing during the pre-treatment period. For longer-term gaps, such as those for Venezuela after 2013, trend-based linear extrapolation is used through 2016, based on the trajectory observed between 2001 and 2013 or 2014. Additionally, the level of social security is measured using the Security Apparatus dataset from the Fragile States Index (FSI). The data are available from 2007 onward and are averaged over the 2007–2016 period. Scores range from 0 to 10, with lower values indicating fewer security threats. This variable is particularly relevant in this region because the presence of illegal armed groups poses significant risks to policy implementation; such groups may attempt to assert territorial control by influencing or interfering with private initiatives in both urban and forested areas (Global Financial Integrity et al., 2025).

For the effect of the associated offsetting mechanism on (c) Tree Cover Loss (%), the outcome variable is defined as the annual percentage of tree cover loss, calculated by dividing the annual tree loss (in hectares) by the extent of tree cover in the year 2000, based on data from Global Forest Watch (2025).

$$\text{Tree Cover Loss (\%)} = \frac{[\text{Annual Tree Cover Loss(Ha)}]}{\text{Tree Cover Extent in 2000(Ha)}} * 100$$

The data used for this study focuses on the total removal or mortality of vegetation taller than 5 meters, applying a minimum canopy cover threshold of 30 percent. Moreover, according to the dataset used for tree cover loss, loss refers to the removal or mortality of tree cover and can result from various factors, including mechanical harvesting, fire, disease, or storm damage, meaning that not only deforestation but also natural disturbances are included, which may inflate measured deforestation rates. Furthermore, improvements in satellite imaging and methodological changes between 2011 and 2015 may have led to higher reported tree cover loss in recent years due to the incorporation of new satellite data and revised methodologies. These factors underscore the need for caution when interpreting tree cover loss data in the context of policy evaluation, particularly when assessing the deforestation-related impacts of Colombia's hybrid carbon tax. For this analysis, the same core socioeconomic predictors used in the CO_2 emissions analyses (a) and (b) are retained to ensure comparability across models. The only exception is the addition of forest area share (%) in 2005, which controls for baseline environmental characteristics across countries—an important factor for analyses focused on the Amazon but not applicable to the CO_2 emissions analysis.

To further enhance the pre-treatment fit in both analyses, lagged values of the outcome variables from the years 2005, 2010, and 2015 are incorporated into the predictor matrix. This approach strengthens the credibility of the counterfactual by ensuring that synthetic Colombia closely mirrors the actual trajectory of the treated unit prior to the introduction of the carbon tax. The complete set of predictor variables and the pre-treatment means for Colombia, synthetic Colombia, and the average of the donor pool are reported in Tables 3, 6, and 9 of the following sections.

V. Results

Based on the methodology and dataset used in this study, this section presents three key findings that evaluate the effectiveness of Colombia's carbon tax policy introduced in 2017. These are organized in the following order: (a) CO_2 emissions excluding Land-Use, (b) CO_2 emissions from oil, and (c) Tree Cover Loss (%). For each outcome, this study provides donor and predictor weight compositions, pre-treatment predictor balance tables, trend figures, and estimated average treatment effects, offering a comprehensive understanding of the policy's short- and medium-term effects across multiple dimensions.

5.1 Hypothesis (a): Impact on CO_2 emissions excluding Land-Use

Country	Weight	Country	Weight
Bolivia	0.573	Venezuela	0
Brazil	0.102	Guatemala	0
Ecuador	0	Costa Rica	0
Guyana	0	Panama	0
Paraguay	0	El Salvador	0.275
Peru	0	Honduras	0.026
Suriname	0	Nicaragua	0.021

Table 1: Main Donor Countries and Their Corresponding Weights for Synthetic Colombia: CO_2 emissions excluding Land-Use [4]

Country	Weight	Country	Weight
ln *GDP pc*	0	Social Security	0.003
Urbanization Ratio (%)	0.008	CO_2 pc excluding LU 2005	0.462
Share of Industry (GDP) (%)	0.001	CO_2 pc excluding LU 2010	0.374
Oil Rent (GDP) (%)	0	CO_2 pc excluding LU 2015	0.147
Fuel Export (%)	0.004		

Table 2: Predictors and Their Corresponding Weights for Synthetic Colombia: CO_2 emissions excluding Land-Use

Tables 1 and 2 present the composition of synthetic Colombia, constructed by minimizing the Mean Squared Prediction Error (MSPE) of the outcome variable during the pre-treatment period. The synthetic control is predominantly composed of Bolivia (57%), El Salvador (27%), and Brazil (10%), while nine other donor countries—whose characteristics diverge more substantially from Colombia's observed data—receive zero

[4] Note: With the synthetic control method, extrapolation is not allowed so all weights are between $0 \leq w_j \leq 1$ and $\Sigma w_j = 1$ wj <1.

weights. According to Abadie (2020), the assignment of zero or highly concentrated weights is not a methodological flaw but rather a common feature of the synthetic control optimization process; indeed, such sparsity may even enhance interpretability.

With this weight distribution, most pre-treatment characteristics of synthetic Colombia resemble those of actual Colombia more closely than the donor pool average. However, discrepancies persist for certain variables, such as oil rent. This arises because oil rent was assigned a predictor weight of zero, and high oil-rent countries like Venezuela, Suriname, and Ecuador did not contribute to the synthetic composition (see Table 3). Nonetheless, the credibility of the estimator largely depends on its ability to reproduce the pre-treatment trajectory of the outcome variable. As shown in Figure 1, the pre-2017 trends in CO_2 emissions excluding land use for both Colombia and its synthetic counterpart are closely aligned, with only minor deviations. This close alignment confirms that the synthetic control provides a credible counterfactual for assessing the impact of Colombia's 2017 carbon tax.

Variables	Colombia	Synth. Colombia	Donor Average
ln $GDP\ pc$	8.468	7.863	8.195
Urbanization Ratio (%)	77.338	70.835	63.033
Share of Industry (GDP) (%)	30.418	29.169	28.498
Oil Rent (GDP) (%)	4.401	3.122	3.171
Fuel Export (%)	50.301	31.111	18.576
Social Security	7.41	6.649	6.089
CO_2 pc excluding LU 2005	1.428	1.451	1.812
CO_2 pc excluding LU 2010	1.703	1.717	2.110
CO_2 pc excluding LU 2015	2.088	1.988	2.190

Table 3: Pre-treatment Predictor Means: CO_2 emissions excluding Land-Use

Based on the optimized pre-treatment fit between Colombia and its synthetic counterpart, the impact of the carbon tax on CO_2 excluding Land-Use is examined by the extent of the divergence in trends between Colombia and its synthetic counterpart following the 2017 policy implementation. Specifically, a decreasing trend in CO_2 emissions is observed in actual Colombia beginning in 2016, when the tax was introduced, and continuing into 2017, the year of its official implementation. However, this reduction appears to be short-lived, suggesting only a temporary impact of the carbon tax. By 2019, emissions in Colombia began to rise again, converging with those of synthetic Colombia. From this point onward, both series exhibit a decline in 2020, likely reflecting the global effects of the COVID-19 pandemic, during which economic activity was widely reduced, leading to a temporary drop in carbon emissions. After that, both series show similar increasing trends and converge to almost the same level of CO_2 emissions, with actual Colombia slightly higher by 0.039 metric tons per capita compared to synthetic Colombia. With these fluctuations, the average treatment effect over the 2017–2023 period is estimated at −0.086 metric tons per capita, which indicates a reduction in emissions as expected, but the magnitude is unexpectedly small.

Overall, while the carbon tax initially contributed to a reduction in CO_2 emissions excluding land use, its impact appears to have been limited and temporary. However, a policy revision in 2023 reduced the allowable use of carbon offsets to 50 percent, which may theoretically lead to different trends or more direct reductions, as the adjustment aims to shift mitigation efforts away from long-term, project-based offsetting toward more immediate emissions cuts. Nevertheless, due to limited data availability, only one year following the policy change is included in the evaluation period, meaning its effects may not yet be fully reflected in the emissions data, underscoring the need for further analysis.

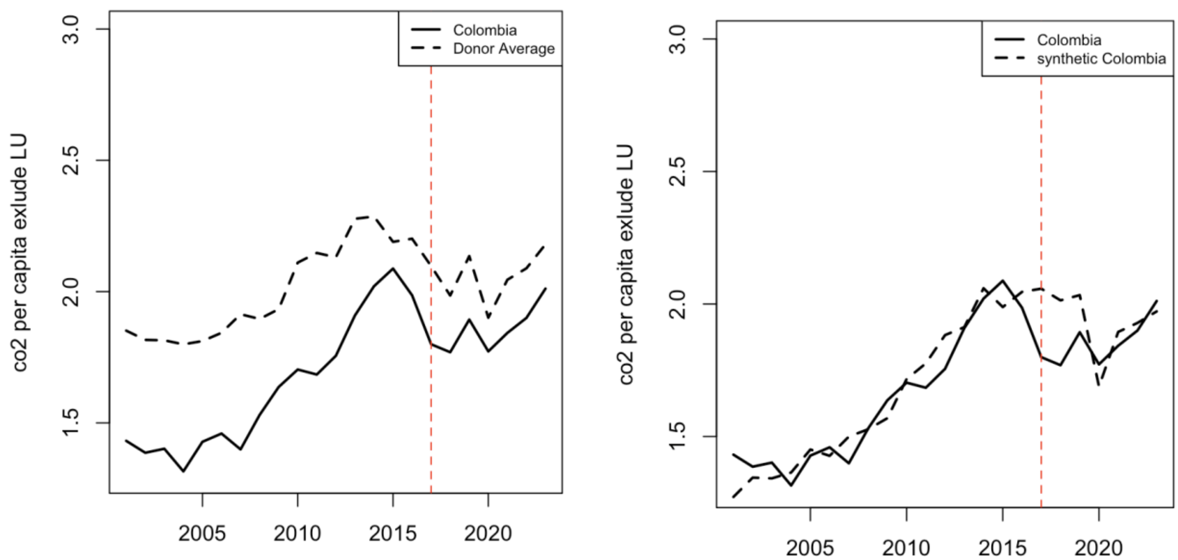

Figure 1: Trends in CO_2 emissions excluding Land-Use:

Colombia vs Donor Average (left) and Colombia vs Synthetic Colombia (right)

5.2 Hypothesis (b): Impact on CO_2 emissions from Oil

Colombia's carbon tax covers products such as gasoline, diesel, kerosene, jet fuel, fuel oil, natural gas used in refining and petrochemical industries, and industrial liquefied petroleum gas (LPG). However, it excludes coal and other solid fuels, meaning the tax applies to only about 31% of the country's total greenhouse gas emissions (Oliveira et al., 2020). Given this partial coverage, using CO_2 emissions excluding Land-Use as an outcome variable may reflect broader emissions trends, including emissions from untaxed sources such as coal and certain uses of natural gas. If the use of untaxed fuels increases as substitutes due to the higher price of taxed fossil fuels, it may dilute the observable impact of the carbon tax in the aggregate emissions indicator used in the initial results. Therefore, to more accurately assess the tax's effect, it is important to analyze CO_2 emissions from oil sector, which more directly captures emissions from the taxed fuel sources. If the trend in oil-related emissions mirrors the trend in (a) CO_2 emissions excluding Land-Use, it would suggest that the carbon tax in Colombia may have contributed to a short-term reduction in emissions across the energy mix, though structural factors such as higher oil rents relative to the synthetic counterpart may also have influenced the results.

Country	Weight	Country	Weight
Bolivia	0.469	Venezuela	0
Brazil	0.044	Guatemala	0
Ecuador	0	Costa Rica	0
Guyana	0.001	Panama	0.170
Paraguay	0	El Salvador	0.315
Peru	0.001	Honduras	0
Suriname	0	Nicaragua	0

Table 4: Main Donor Countries and Their Corresponding Weights for Synthetic Colombia: CO_2 emissions from Oil[5]

Country	Weight	Country	Weight
ln *GDP pc*	0.003	Social Security	0
Urbanization Ratio (%)	0.002	CO_2 pc from Oil 2005	0.321
Share of Industry (GDP) (%)	0.009	CO_2 pc from Oil 2010	0.509
Oil Rent (GDP) (%)	0.008	CO_2 pc from Oil 2015	0.145
Fuel Export (%)	0.003		

Table 5 : Predictors and Their Corresponding Weights for Synthetic Colombia: CO_2 emissions from Oil

Tables 4 and 5 detail the composition of synthetic Colombia, constructed by minimizing the Mean Squared Prediction Error (MSPE) of the outcome variable during the pre-treatment period. The synthetic control is primarily composed of Bolivia (46%), El Salvador (31%), and Panama (17%), while eight other donor countries receive zero weights and contribute negligibly to the final estimate. As noted by Abadie (2020),

[5] Note: With the synthetic control method, extrapolation is not allowed so all weights are between $0 \leq w_j \leq 1$ and $\Sigma w_j = 1$ wj <1.

the assignment of zero or highly concentrated weights is not a methodological flaw but rather a common feature of the synthetic control optimization process.

With this weight distribution, most pre-treatment characteristics of synthetic Colombia resemble those of actual Colombia more closely than the donor pool average. Yet, similar to the results for (a) CO_2 emissions excluding land use, the gap for variables such as oil rent remains slightly larger. This is because the predictor weight assigned to oil rent is very low, and countries with relatively high oil rent values—such as Venezuela, Suriname, and Ecuador—are not included in the synthetic composition (see Table 6). However, given the close alignment between Colombia and its synthetic counterpart in pre-treatment CO_2 emissions from oil (see Figure 2), the synthetic control provides a credible counterfactual for assessing the impact of the 2017 carbon tax.

Variables	Colombia	Synth. Colombia	Donor Average
$\ln GDP\ pc$	8.468	7.874	8.195
Urbanization Ratio	77.338	68.473	63.033
Share of Industry (GDP)	30.418	30.751	28.498
Oil Rent (GDP) (%)	4.401	2.132	3.171
Fuel Export (%)	50.301	30.911	18.576
Social Security	7.410	6.591	6.089
CO_2 pc from Oil 2005	0.734	0.755	1.480
CO_2 pc from Oil 2010	0.797	0.826	1.736
CO_2 pc from Oil 2015	1.010	0.949	1.726

Table 6: Pre-treatment Predictor Means: CO_2 emissions from Oil

The impact of the carbon tax on oil-related CO_2 emissions is examined by the extent of the divergence in trends between Colombia and its synthetic counterpart following the 2017 policy implementation. With the more targeted scope of the tax, this indicator shows a clearer but short-lived gap compared to CO_2 emissions excluding land use. Specifically, a decline in Colombia's CO_2 emissions from oil begins in 2016, when the tax was introduced, and continues through its official implementation in 2017. While a global drop in oil prices during this period may have contributed to the decline, such effects were largely universal across all countries, including those in the donor pool. Therefore, the observed initial reduction can still be reasonably interpreted as linked to the tax implementation. Following this period, Colombia's emissions converged with those of the synthetic control. Subsequently, oil-related emissions in Colombia surpassed those of the synthetic control by 0.127 metric tons per capita. This brief decline followed by a rebound results in an average treatment effect of −0.064 metric tons per capita over the 2017–2023 period.

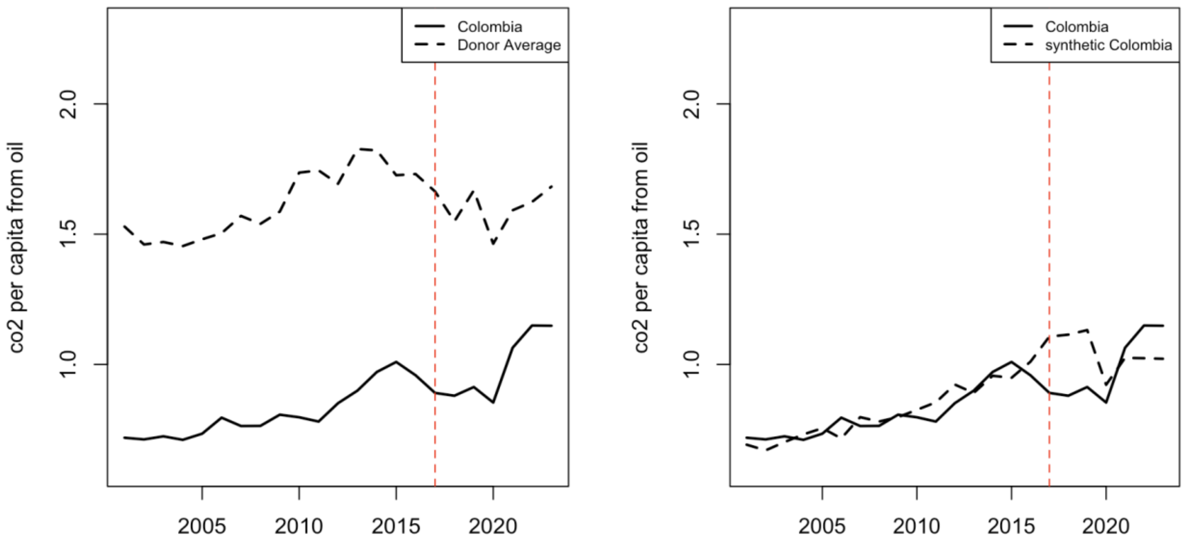

Figure 2: Trends in CO_2 emissions from Oil:
Colombia vs Donor Average (left) and Colombia vs Synthetic Colombia (right)

Overall, the policy appears to have generated a noticeable reduction, but this effect quickly diminished, suggesting that the reduction observed in result (a) is unlikely to be explained by fuel substitution toward untaxed alternatives such as coal. Rather, the findings imply that the tax failed to achieve sustained behavioral or structural changes even within the taxed fuel categories, pointing to limitations in its long-term effectiveness. The policy revision in 2023, however, which reduced the allowable use of carbon offsets, may not yet be fully reflected in the emissions data. Thus, this unexpected pattern, together with the evolving policy context, suggests the need for further investigation.

5.3 Hypothesis (c): Impact on Tree Cover Loss (%)

Deforestation is not directly regulated by Colombia's carbon tax, yet it is closely linked to the policy as a large share of tax liabilities could be offset through carbon credits—initially up to 100 percent and since 2023 limited to 50 percent. Particularly, as the 25th largest nation in the world and one of the world's megadiverse countries, Colombia is covered by forests across more than half of its territory (OECD, 2025). This ecological structure likely created strong incentives for companies to invest in carbon credit projects, such as those under REDD+, when such investments were more financially advantageous than paying the carbon tax directly. While carbon credits can be generated through multiple project types, this study employs tree cover loss as a proxy for offsetting activity. If a significant reduction in tree cover loss were observed, it could help explain the limited or short-lived impact of the carbon tax on direct CO_2 emissions in cases (a) and (b), as firms may have shifted toward carbon credit projects that primarily generate long-term benefits.

Country	Weight	Country	Weight
Bolivia	0.051	Venezuela	0.001
Brazil	0.093	Guatemala	0.001
Ecuador	0	Costa Rica	0.047
Guyana	0.501	Panama	0
Paraguay	0	El Salvador	0.067
Peru	0	Honduras	0.005
Suriname	0.003	Nicaragua	0.231

Table 7: Main Donor Countries and Their Corresponding Weights for Synthetic Colombia: Tree Cover Loss[6]

Country	Weight	Country	Weight
ln *GDP pc*	0.156	Social Security	0.006
Urbanization Ratio (%)	0.010	Forest Area 2005	0.172
Share of Industry (GDP) (%)	0.011	CO_2 pc excluding LU 2005	0.074
Oil Rent (GDP) (%)	0	CO_2 pc excluding LU 2010	0.122
Fuel Export (%)	0.301	CO_2 pc excluding LU 2015	0.148

Table 8 : Predictors and Their Corresponding Weights for Synthetic Colombia: Tree Cover Loss

Tables 7 and 8 detail the composition of synthetic Colombia, constructed by minimizing the Mean Squared Prediction Error (MSPE) of the outcome variable during the pre-treatment period. The synthetic control is primarily composed of Guyana (50%), Nicaragua (23%), and Brazil (9.3%), while four other donor countries receive zero weights and therefore make negligible contributions. As noted previously, the assignment of zero or highly concentrated weights is not a methodological flaw but a typical feature of the synthetic control optimization process.

Consistent with earlier analyses, most pre-treatment characteristics of synthetic Colombia resemble those of actual Colombia more closely than the donor pool average. However, the gap for variables such as oil rent remains relatively larger, as countries with high oil rent values—such as Venezuela, Suriname, and

[6] Note: With the synthetic control method, extrapolation is not allowed so all weights are between $0 \leq w_j \leq 1$ and $\Sigma w_j = 1$ wj <1.

Ecuador—are either excluded or assigned very low weights (see Table 9). While this imbalance is not ideal, the core criterion for credibility lies in the counterfactual's ability to reproduce the pre-treatment trajectory of the outcome variable, which is well achieved here, as shown in Figure 3. Interestingly, both Colombia and its synthetic counterpart exhibit a marked increase in tree cover loss starting around 2015. While the earlier rise between 2011 and 2015 may be largely attributed to improvements in satellite imaging and data detection, the continued increase beyond 2015 suggests a genuine uptick in deforestation across Central and South America, indicating broader regional dynamics at play.

Variables	Colombia	Synth. Colombia	Donor Countries
ln $GDP\ pc$	8.468	8.467	8.195
Urbanization Ratio	77.338	71.372	63.033
Share of Industry (GDP)	30.418	34.187	28.498
Oil Rent (GDP) (%)	4.401	10.614	3.171
Fuel Export (%)	50.301	50.047	18.576
Social Security	7.410	6.584	6.089
Forest Area 2005	55.675	55.617	57.625
Tree loss percentage 2005	0.231	0.254	0.506
Tree loss percentage 2010	0.241	0.243	0.620
Tree loss percentage 2015	0.172	0.182	0.342

Table 9: Pre-treatment Predictor Means: Tree Cover Loss (%)

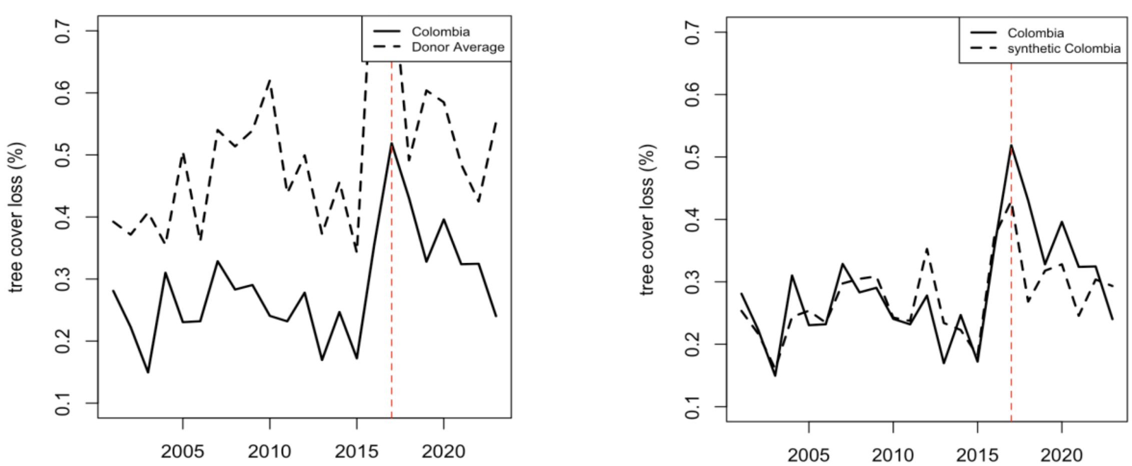

Figure 3: Trends in Tree Cover Loss (%): Colombia vs Donor Average (left) and Colombia vs Synthetic Colombia (right)

Looking at the trends between Colombia and its synthetic counterpart following the 2017 policy implementation, Colombia's tree cover loss remained higher, with fluctuations through 2022, but followed a generally similar declining trajectory to that of the synthetic control. Unlike the previous two indicators, which exhibited temporary divergence, the trajectory of tree cover loss does not show a similar pattern. Instead, the gap between Colombia and its synthetic control gradually narrowed after the policy intervention, ultimately resulting in 0.053 percentage points lower deforestation in Colombia. However, due to this slow adjustment, the average treatment effect over 2017–2023 is estimated at 0.054 percentage points higher tree cover loss in Colombia compared to the synthetic control.

Overall, although Colombia's lower deforestation in 2023 represents a positive development, the persistently higher percentage of tree cover loss raises concerns about the initial design and management of carbon crediting projects. This aligns with critiques by Wang-Helmreich and Kreibich (2019) and Dufrasne (2021), who cautioned that offsetting schemes—particularly those under REDD+—may fail to deliver verifiable emission reductions without robust regulation, thereby jeopardizing both environmental and fiscal integrity. However, with the recent policy revision reducing the allowable use of carbon offsets to 50 percent, these trends could shift again. Therefore, continued monitoring and rigorous evaluation are essential to ensure the policy achieves its intended objectives.

5.4 Robustness Tests

To further test the validity of the results, this study conducted a series of robustness tests. Within the context of SCM, robustness is commonly evaluated through placebo-based inference, which involves reassigning the treatment to other control units or years to examine whether the observed effect for the treated unit is distinct from those of placebo-treated units. However, this approach has several limitations. In practice, researchers often exclude poorly fitted units using a Mean Squared Prediction Error (MSPE) threshold to improve comparability, though this may overstate significance (Ferman & Pinto, 2017). Moreover, when the donor pool is small, the minimum attainable p-value (1/N) can be highly sensitive to small variations (Lei & Sudijono, 2024). Even so, since traditional large-sample inference is not applicable in SCM, placebo-based inference remains a practical and transparent tool to assess whether the estimated effects reflect a genuine policy impact (Abadie et al., 2010). Accordingly, this study performs placebo tests as a primary robustness check.

To complement its placebo tests, this study also employs a leave-one-out (LOO) analysis, which systematically removes one donor country with a positive weight at a time and re-estimates the treatment effect to ensure that the results are not driven by any single donor. This approach is particularly valuable for assessing the robustness of the findings to variations in donor composition (Liu et al., 2025), especially in cases where the number of weighted units is relatively small. To further assess the robustness of the findings, this study alters both the donor pool and predictor specifications, testing the sensitivity of the estimated treatment effects to alternative model setups (Arcila & Baker, 2022; Bretschger & Grieg, 2024; Abadie, 2020). By re-estimating the model with alternative sets of countries and predictors, this analysis evaluates whether the main conclusions remain consistent across different specifications, thereby enhancing the credibility of the empirical results.

5.4.1 Placebo in Time

For the in-time test, the year of treatment was shifted to 2008, which is prior to the actual treatment year of 2017. The same predictors were used, but the lagged outcome variables were adjusted accordingly. For instance, the lagged outcome variables previously set to 2005, 2010, and 2015 were replaced with 2001, 2004, and 2007. The purpose of this test, as the name suggests, is to confirm that a placebo treatment would not produce a post-placebo divergence in the trajectory of emissions or tree loss between Colombia and its synthetic control. A large divergence in the placebo year of 2008, which was not associated with any actual policy implementation, would cast doubt on the validity of the results shown in Figures 1, 2, and 3, which display a short-term reduction in CO_2 emissions and an unexpected increase in tree loss that later declined.

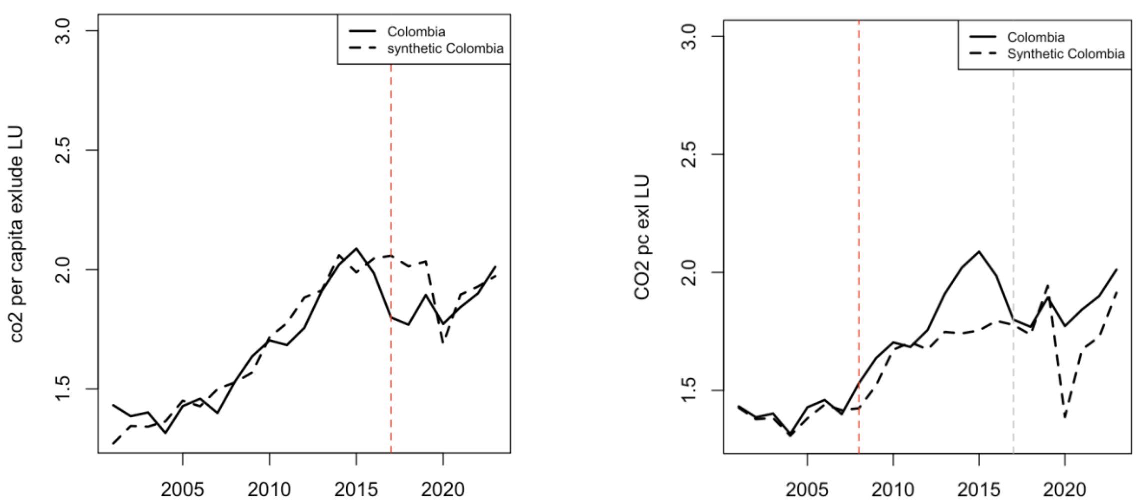

Figure 4: Placebo-in-time test for CO_2 emissions excluding Land-Use: Actual 2017 Policy Implementation (left) vs. Placebo-in-time test (right)

Looking at the in-time test of the first results, namely CO_2 emissions excluding Land-Use (Figure 4, right), although the paths diverge from 2008 in the right panels, the effect appears more random over the 2008–2023 period compared to the actual policy implementation in 2017 (left panels), where the divergence is more immediate and clearly visible around the policy year. Likewise, regarding CO_2 emissions from oil, the effect appears more random over the 2008–2023 period compared to the actual policy implementation in 2017 (left panels). For the tree loss placebo-year test (Figure 6), the divergence between 2008 and 2023 in the right panel also appears more random than the immediate and pronounced divergence observed around 2017 in the left panel. Overall, the patterns observed under this placebo intervention in 2008 in figures 4,5, and 6 are consistent with what would be expected if the estimation strategy is valid, as no systematic and sustained divergence is detected in the absence of the actual policy.

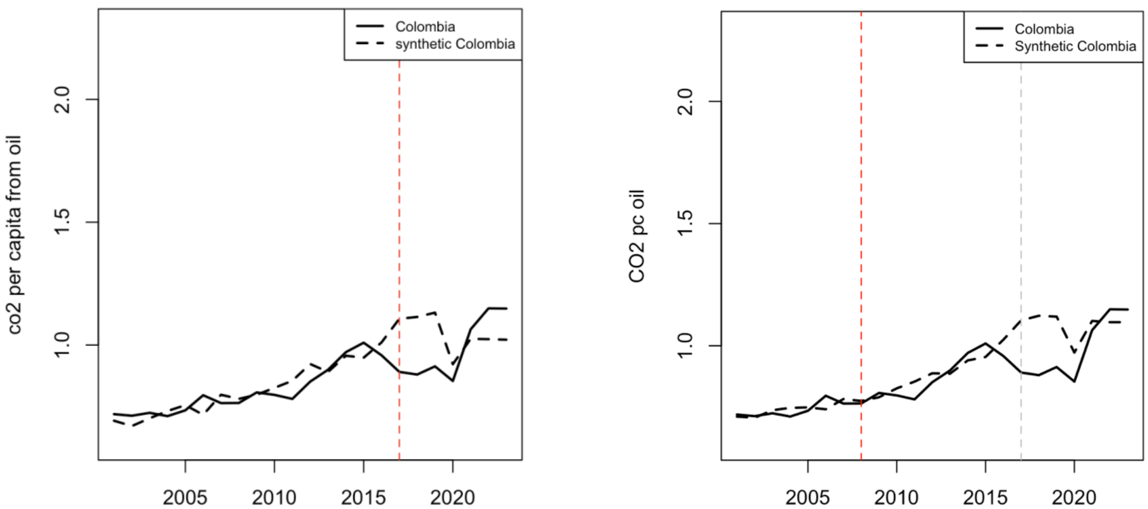

Figure 5: Placebo-in-time test for CO_2 emissions from Oil:

Actual 2017 Policy Implementation (left) vs. Placebo-in-time test (right)

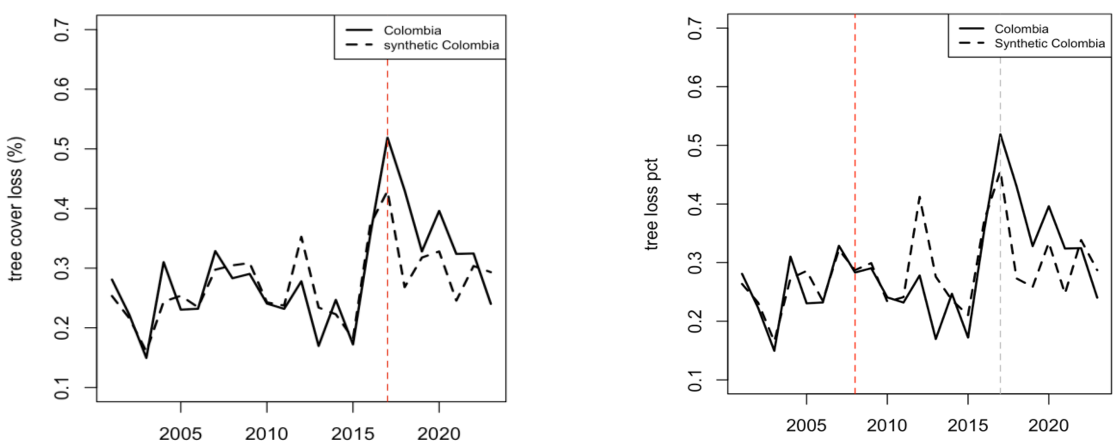

Figure 6: Placebo-in-time test for Tree Cover Loss (%):

Actual 2017 Policy Implementation (left) vs. Placebo-in-time test (right)

5.4.2 Placebo in Space

For the in-space placebo test, the treatment is iteratively reassigned to each country in the donor pool, and SCM is used to construct synthetic counterparts for them. For example, this test constructs a "synthetic

Brazil" as if it had implemented a carbon tax, even though it did not. This process is repeated for all donor countries, as was done for Colombia. Similar to the in-time test, this procedure evaluates whether Colombia's results are unusually large compared to placebo results for all countries in the donor pool. As is standard in SCM research, countries with a large pre-treatment Mean Squared Prediction Error (MSPE) are filtered out. While the choice of an MSPE cutoff is arbitrary and varies across studies, this analysis applies a threshold of at least 20 times Colombia's pre-treatment MSPE.

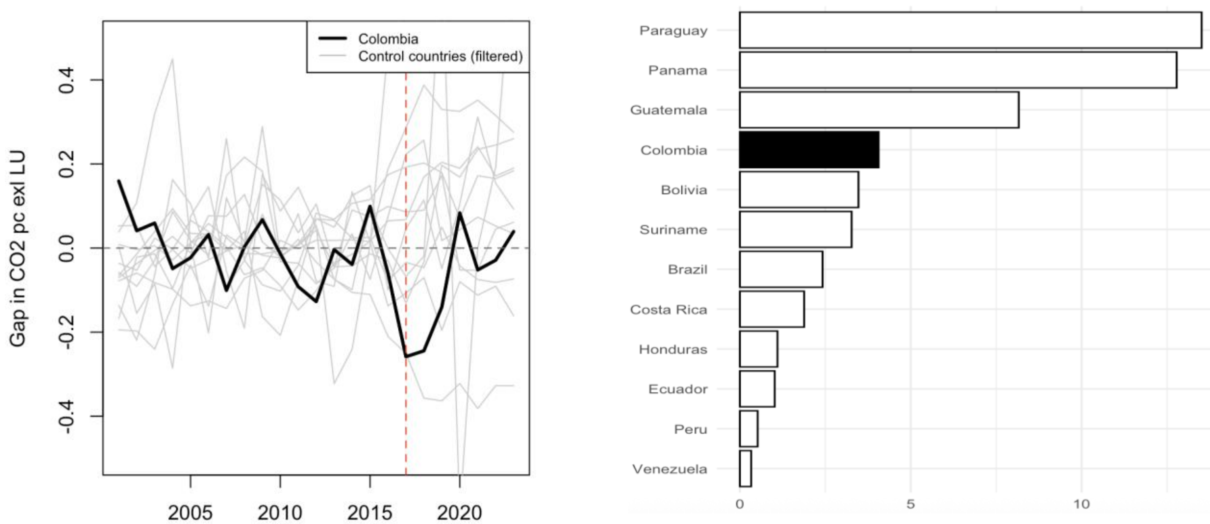

Figure 7: Placebo-in-space test for CO_2 emissions excluding Land-Use: Country-specific gaps (left) and Post-/Pre-treatment MSPE ratios (right)

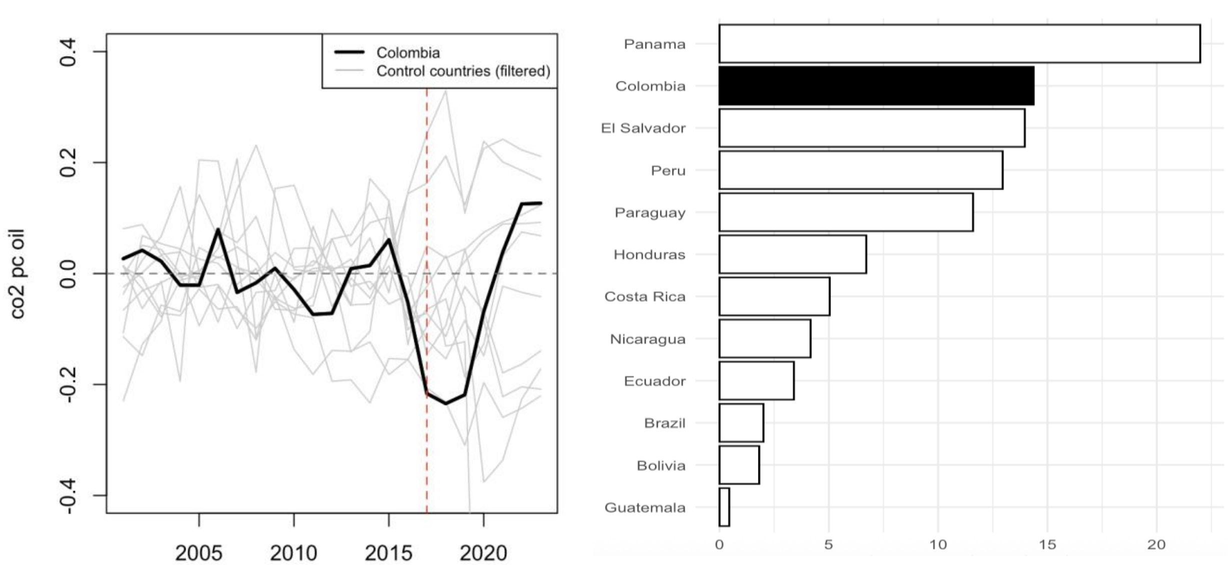

Figure 8: Placebo-in-space test for CO_2 emissions from Oil: Country-specific gaps (left) and Post-/Pre-treatment MSPE ratios (right)

With this MSPE threshold, 11 countries remain in the donor pool for CO_2 emissions excluding Land-Use. Figure 7 (left) depicts the path of Colombia (black line) and the control countries assigned the placebo treatment (grey lines). At the beginning of the policy implementation in 2017, Colombia recorded the largest reduction; however, as shown in Figure 1, the reduction became progressively smaller over time and was eventually reversed after the COVID-19 pandemic. Consequently, over time, Colombia's effect relative to other countries became comparatively smaller. Therefore, as shown in Figure 7 (right), Colombia's post-/pre-treatment MSPE ratio is relatively low, corresponding to a probability of 4/12 = 0.333 of observing a ratio of equal or greater magnitude under random treatment assignment. This suggests that the overall post-treatment effect on CO_2 emissions excluding Land-Use is not statistically significant, which aligns with prior expectations.

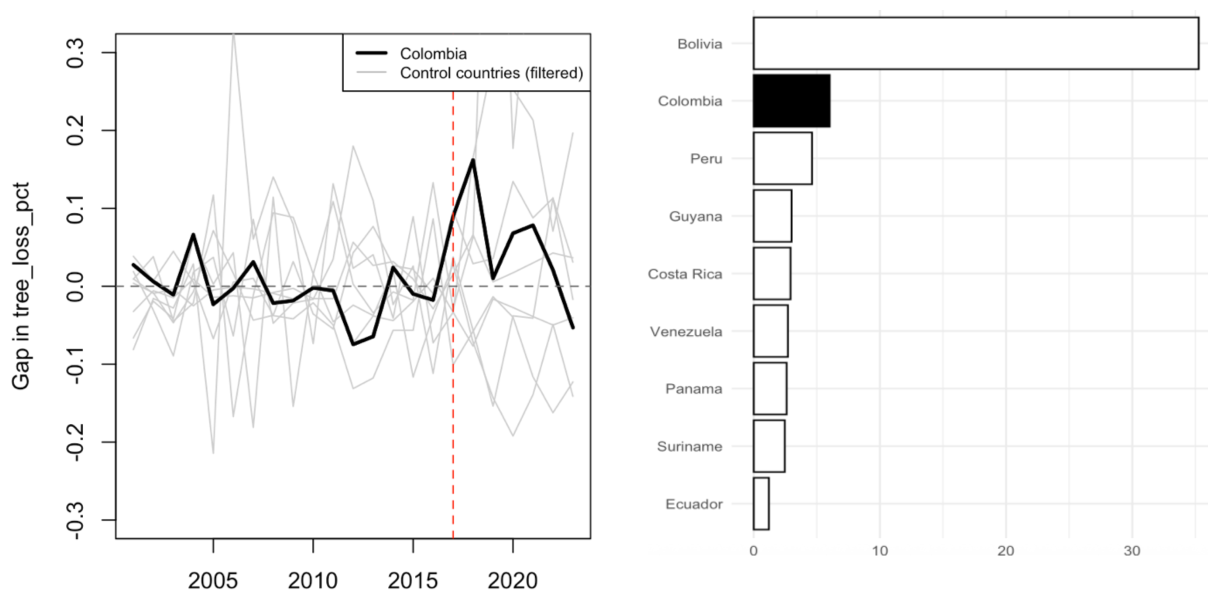

Figure 9: Placebo-in-space test for Tree Cover Loss (%): Country-specific gaps (left) and Post-/Pre-treatment MSPE ratios (right)

Similarly, for CO_2 emissions from oil, the same MSPE threshold leaves 11 countries in the donor pool. As shown in Figure 8 (left), at the start of the policy implementation in 2017, Colombia again recorded the largest reduction. However, as shown in Figure 2, the effect was subsequently reversed following the COVID-19 pandemic. Over time, Colombia's effect relative to other countries diminished further. This pattern is further reflected in the post-/pre-treatment MSPE ratio. In Figure 8 (right), Colombia's post-/pre-treatment MSPE ratio ranks second highest, with the probability of observing a ratio as large as Colombia's being 2/12 = 0.167. This result is more significant than the first, due to the more direct coverage of the carbon tax. However, Colombia's ratio remains substantially smaller than Panama's, and when compared with El Salvador and Peru, the magnitude of this MSPE would not be considered significantly high.

Therefore, as expected, the overall post-treatment effect on CO_2 emissions from oil remains statistically insignificant, consistent with prior expectations.

For tree cover loss, applying the MSPE filter leaves eight countries in the donor pool. As observed in Figure 9 (left), Colombia experienced unexpectedly high levels of tree cover loss at the outset of the post-treatment period, followed by a gradual decline in subsequent years. This trajectory results in Colombia's post-/pre-treatment MSPE ratio ranking second among the remaining donor countries, corresponding to a probability of 2/9 = 0.222 of observing a ratio of equal or greater magnitude under random treatment assignment. In other words, the magnitude of Colombia's MSPE would not be considered significantly high, which is consistent with the results for CO_2 emissions, reinforcing the conclusion that the carbon tax and offsetting mechanism had only a limited impact on this outcome during the study period.

5.4.3 Leave-one-out

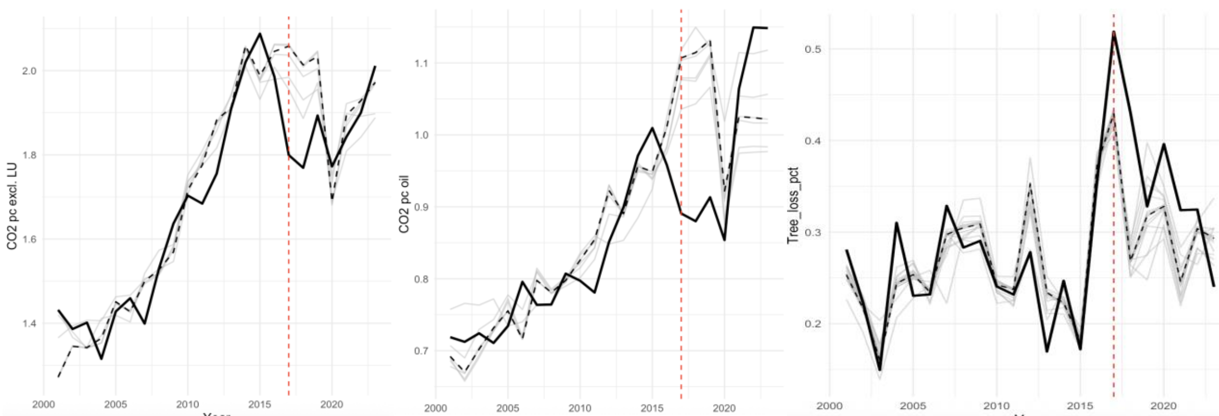

Figure 10: Leave-one-out results: CO_2 emissions excluding Land-Use (left), CO_2 emissions from oil (center), and Tree Cover Loss (right).

The leave-one-out (LOO) robustness test was conducted by sequentially excluding each donor country with an assigned weight of at least 0.001 to assess whether the estimated effects are driven by any single influential donor. For CO_2 emissions excluding Land-Use, five donors — Bolivia, Brazil, El Salvador, Honduras, Nicaragua — had weights above this threshold. The results (Figure 10, left) show that the grey lines, representing the exclusion of individual donors, largely follow the same trajectory as the synthetic control (dashed line), with only minor deviations in certain years. This indicates that the policy effect estimates are not substantially influenced by any single donor and remain stable across all exclusions. For CO_2 emission from oil, six donors — Bolivia, Brazil, Guyana, Peru, Panama, El Salvador — met the threshold. As shown in Figure 10 (center), the grey lines almost entirely overlap with the synthetic control line, indicating strong robustness despite the smaller number of donor countries. Likewise, in terms of tree cover loss, ten donors—Bolivia, Brazil, Guyana, Suriname, Venezuela, Guatemala, Costa Rica, El Salvador, Honduras, Nicaragua—met the threshold. While the exclusion of some donors results in slightly greater post-treatment fluctuations (Figure 10, right), the overall trajectory remains consistent with the main estimate. These findings confirm that the main results are not driven by the exclusion of any single donor country.

5.4.4 Changed Donor Pool and Predictors

To assess the sensitivity of the estimated treatment effects to alternative model settings, this study also alters the donor pool and the predictor set. For the donor pool, the set of candidate countries for the counterfactual was restricted to South American nations only, namely Bolivia, Brazil, Ecuador, Guyana, Paraguay, Peru, Suriname, and Venezuela. As shown in Figure 11, the results based on this restricted donor pool remain nearly identical to the baseline findings. Both the gap and path plots exhibit similar trajectories to the main results, with only a slightly larger reduction in CO_2 emissions excluding land use observed in 2016 and 2017 in the original study.

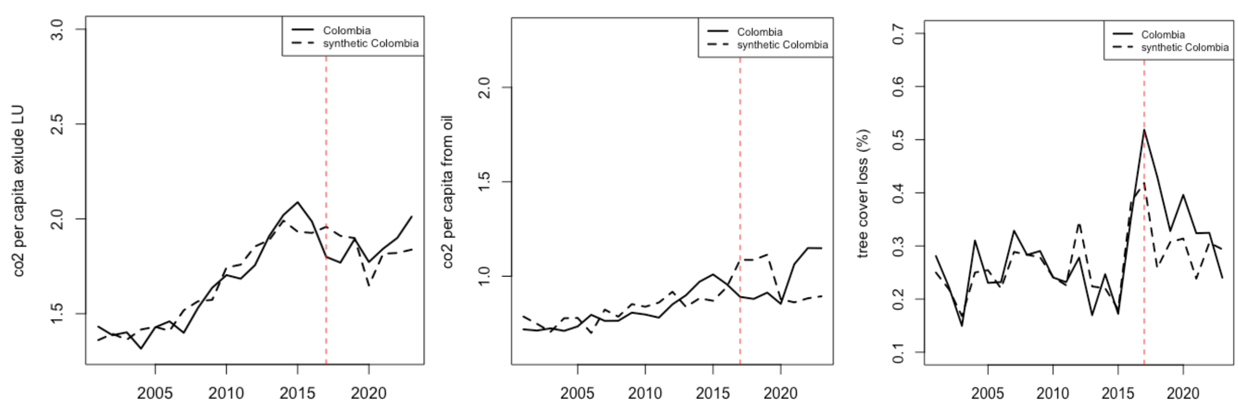

Figure 11: Changed Donor Pool: CO_2 emissions excluding Land-Use (left), CO_2 emissions from Oil (center), and Tree Cover Loss (right).

For the predictors, the model incorporated alternative but conceptually similar variables. Specifically, the urbanization ratio was replaced with the logarithm of population (World Bank) and per capita energy use (U.S. Energy Information Administration, 2025). The share of industry in GDP was substituted with the share of agriculture in GDP (World Bank), and the social security indicator from the Fragile States Index (FSI) was replaced with the Political Stability and Absence of Violence/Terrorism index (World Bank). As with the donor pool adjustment, the results obtained from this alternative predictor specification remain consistent with the main findings, with both the path and gap plots showing highly similar trends (see Figure 12). Overall, these robustness checks confirm that the results are not driven by a particular donor composition or predictor specification, thereby reinforcing the stability and credibility of the initial methodological setup.

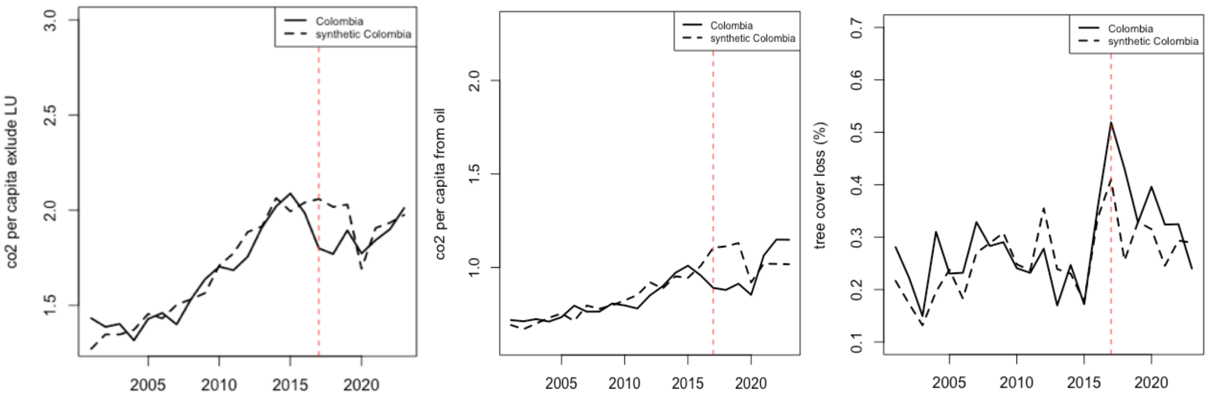

Figure 12: Changed Predictors: CO_2 emissions excluding Land-Use (left), CO_2 emissions from Oil (center), and Tree Cover Loss (right).

VI. Discussion

The previous section presented the quantitative findings of the synthetic control analysis, which indicated that Colombia's carbon tax and its offsetting mechanism have not led to statistically significant reductions in CO_2 emissions or deforestation since their introduction. These results call for a closer examination of the underlying factors contributing to this limited effectiveness. Accordingly, the following section draws on relevant literature to identify the key factors behind the modest policy outcomes and to propose potential improvements that could enhance their future impact.

6.1 Challenges of the Carbon Tax Design

Drawing on academic research, policy documents, and official reports, this study identifies several design and regulatory shortcomings in Colombia's carbon tax system that help explain its limited impact that was shown in the empirical results. The following subsections outline key structural challenges—such as a low tax rate, narrow sectoral scope, continued fossil fuel subsidies, and the dilution of price signals through offsetting mechanisms—that have collectively undermined the policy's effectiveness.

6.1.1 Low Tax Rate

The first key factor behind the limited effects on carbon reduction—both in CO_2 emissions excluding Land-Use and CO_2 emissions from oil—identified in this study appears to stem from the low level of the carbon tax rate. From an economic perspective, a carbon tax should provide a sufficiently strong price signal to internalize the external costs of emissions and induce behavioral change among emitters. However, Colombia's carbon tax remains at approximately USD 5–7 per ton, which is substantially below the benchmark range of USD 40–80 per ton by 2020 and USD 50–100 per ton by 2030 recommended by the World Bank's High-Level Commission on Carbon Prices for Paris Agreement alignment (World Bank, 2021; Stiglitz et al., 2017). Therefore, increasing the tax rate toward internationally recommended levels would be an essential next step for Colombia's carbon tax to achieve effective mitigation outcomes. However, a price increase is not a panacea. As seen in Australia, raising the tax rate too sharply can lead to socioeconomic side effects that may ultimately undermine environmental objectives. In the current structure, Colombia's carbon tax revenue is designated—25% for climate mitigation efforts, 5% for protected areas, and 70% for post-conflict development projects. To guarantee equity within this structure, it is also necessary to carefully review whether a tax increase would place a disproportionate burden on poor populations. If so, additional revenue generated from higher tax rates should be considered and utilized effectively—for instance, by returning a portion as household rebates and providing additional assistance to vulnerable groups (Stiglitz et al., 2017).

6.1.2 Limited Coverage and Coal Exemption

As seen in the comparison between (a) CO_2 emissions excluding Land-Use and (b) CO_2 emissions from oil, the more narrowly taxed category shows a clearer directional effect, though this impact is only short-term. This suggests that the scope of tax exemptions would play a critical role in shaping the effectiveness of a carbon tax. In Colombia, one of the key exemptions affecting (a) CO_2 emissions excluding land use is coal—its sixth-largest export commodity. This exemption from the carbon tax since its introduction, largely the result of lobbying by sectoral interest groups (Giovanni et al., 2022), narrows the tax base and undermines the policy's overall environmental effectiveness. Although the comparison between findings (a) and (b) in this study shows no significant shift toward increased coal use, projected declines in international coal prices for 2024–2026 (Agnolucci et al., 2024; Agnolucci & Makarenko, 2025) may incentivize greater domestic coal consumption beyond the 2023 study period. In recognition of this risk, the Colombian government has announced plans to extend the carbon tax to coal-fired power generators and industrial users from 2025—a reform expected to generate fiscal revenues of approximately 0.03 percent of GDP (Fergusson & Hofstetter, 2022; Argus Media, 2025a). Yet the full implementation of the carbon tax on coal will be phased in gradually through the end of 2027 (BDO, 2023), which may delay the realization of its full environmental benefits. Moreover, the expansion presents policy trade-offs, as coal remains a critical backup energy source during hydropower shortages (Fergusson & Hofstetter, 2022; IEA, 2023). To improve its limited effects, Colombia should therefore move more quickly to include not only coal but also other exempted materials in the carbon tax. At the same time, to safeguard energy security, it will be essential to carefully monitor the tax's implementation and invest in alternative renewable energy sources to reduce reliance on fossil fuel–based backup energy.

6.1.3 Fossil Fuel Subsidies

To explain why the effectiveness of Colombia's carbon tax appears short-term, it is necessary to consider the role of fossil fuel subsidies. In Colombia, the government continues to provide substantial subsidies for gasoline and diesel consumption, which increased significantly during the COVID-19 pandemic compared to other countries in the donor pool. This rise likely counteracts the environmental benefits of the carbon tax (IMF, n.d.), thereby diminishing its long-term impact, as reflected in this study (a) and (b). Specifically, even before the COVID-19 pandemic, according to the UNEP dataset (n.d.), Colombia ranked among the highest countries in per capita fossil fuel subsidies, with its increasing trend surpassing Brazil's decline and reaching fourth overall—behind only Venezuela, Suriname, and Ecuador. Reversing this upward trend has become increasingly infeasible, as poverty rates rose sharply from 35.5 percent in 2019 to 42.5 percent in 2020 following the pandemic (Baquero et al., 2023), prompting the government to expand fuel subsidies from USD 20.71 to USD 79.28 per capita to stabilize fuel prices (UNDESA, 2023). As in many developing countries, rising fuel subsidies during the COVID-19 pandemic were unavoidable to protect vulnerable groups from disproportionately high energy costs. However, because Colombia already had among the highest subsidy levels even before the pandemic, this further increase likely constrained the effectiveness of its carbon tax. Therefore, to strengthen the carbon tax's effectiveness, fossil fuel subsidies should be gradually adjusted while cushioning the impact on low-income populations through alternative support measures or by redistributing carbon tax revenues.

6.1.4 Dilution of Effectiveness through Offsetting

Beyond the design of the tax structure itself, an additional factor that helps explain the limited effectiveness of Colombia's carbon tax observed in this study is its hybrid mechanism. Under this system, as mentioned, emitters are allowed to meet their obligations either by paying the tax or by purchasing carbon offsets. In practice, many private companies have opted to buy REDD+ credits, which has stimulated growth in the domestic offset market. However, unlike the government-set tax rate, the price of carbon credits is market-driven and has remained substantially lower—averaging around USD 4 per ton since 2021 (Smith, 2025). This price gap between the carbon tax and offset credits creates a strong incentive for firms in Colombia to comply through offsetting, as reflected in the post-2021 trends observed in this study, lowering the internalized price of carbon and weakening incentives for direct emissions reductions. In recognition of these limitations, Colombia revised its carbon tax framework in 2023 by introducing a cap that limits the use of offsets to 50 percent of a firm's total tax obligations. This measure has strengthened the tax's direct impact and reduced uncertainties associated with offset markets (Argus Media, 2025b). Nevertheless, even with a reduced share of offsetting since 2023, the market-based nature of carbon credit pricing may continue to undermine the effectiveness of the tax if the price of credits remains significantly lower than the tax rate. Thus, the government should carefully monitor carbon credit projects to prevent the creation of overinflated credits that could depress overall prices, while also reviewing potential spillover effects from the reduced offsetting share.

6.2 Challenges of the Offsetting Mechanism

Beyond tax-related challenges in Colombia, this study also identifies several design and implementation shortcomings in the country's offsetting mechanism that help explain its limited effectiveness. The following subsections outline key systemic challenges—such as weak institutional capacity, misaligned stakeholder incentives, insufficient binding regulations, and social and human rights risks within REDD+ projects—that have collectively constrained the credibility and overall impact of the policy.

6.2.1 Weak Institutional Capacity in REDD+ Governance

To enhance the effectiveness of its offsetting framework, the government introduced Resolution 1447 in 2018, aligning it with the national REDD+ strategy and establishing stricter MRV and accounting rules. However, as reflected in this study's findings on tree cover loss, deforestation in Colombia has not decreased substantially compared to its synthetic counterparts. Of the several factors involved, weak institutional capacities have constrained progress, resulting in overinflated credit estimates, monitoring deficiencies, and the issuance of "hot air" credits (Dufrasne, 2021). For instance, under Resolution 1447, the RENARE system — the official online registry — was introduced, but its delayed and inconsistent operation has undermined transparency and raised concerns about credibility. The Matavén project, for example, reportedly continued selling credits for at least four years despite not appearing in the updated registry (Dufrasne, 2021; Bermúdez Liévano, 2021; Global Financial Integrity et al., 2025). Even when active, RENARE has largely functioned as a data repository rather than a robust verification system, leaving project developers responsible for ensuring data accuracy (Global Financial Integrity et al., 2025). Additionally, verification practices have been weak. In the Pirá Paraná project, for example, verifiers relied solely on satellite imagery without conducting any on-site inspections (Global Financial Integrity et al., 2025). It should be noted, however, that carbon credits and carbon taxes are not necessarily opposing mechanisms; rather, they can complement each other when properly integrated from the outset, supporting both carbon emissions reductions and forest conservation. To achieve this, future policy discussions should not only consider narrowing the scope of the hybrid system but also focus on strengthening existing mechanisms to improve the overall effectiveness of Colombia's hybrid carbon tax framework.

6.2.2 Misaligned incentives among Actors

In parallel with institutional capacity, the limited effectiveness in reducing tree cover loss observed in this study can also be attributed to structural flaws inherent in the offset mechanism itself. In the case of Colombia, although REDD+ is intended to prioritize social and environmental benefits, misaligned incentives among various stakeholders—such as landowners, carbon credit buyers, and certification entities—may have further undermined the policy's effectiveness in implementing REDD+ projects aimed at curbing deforestation (van Kooten, 2017). For instance, landowners are interested in maximizing immediate net returns from land use, while buyers often assume that credits are legitimate and truly reduce atmospheric emissions, which weakens incentives for independent verification. Validation and Verification Bodies (VVBs) also lack sufficient independence from project developers, as verification entities often maintain lenient oversight to preserve future business relationships, creating conflicts of interest that enable practices such as inflated baselines or overstated emission reductions (Global Financial Integrity et al., 2025). To shift misaligned stakeholder incentives toward greater environmental integrity, it would be beneficial to expand the use of tools such as results-based crediting schemes, which directly link payments to verified emission reductions. Building on this, it is also essential to ensure credible validation and verification processes, including stricter independence requirements for VVBs and the adoption of multiple verification mechanisms.

6.2.3 Insufficient Binding Regulations

To enhance the effectiveness of carbon credit initiatives, which were found to have limited impact in this study, it would be also essential to strengthen environmental safeguards under REDD+. This is because the current inadequacy of regulatory frameworks governing these projects can create vulnerabilities to corruption, double counting, and data manipulation (Dufrasne, 2021; Transparencia Mexicana et al., 2013). In Colombia specifically, even publicly funded programs are not subject to mandatory compliance, reflecting a broader weakness in regulatory enforcement (Global Financial Integrity et al., 2025). If this trend continues without binding legal obligations and effective enforcement mechanisms, it will be particularly concerning for the principle of additionality, as it undermines the credibility and environmental integrity of REDD+ initiatives and may further exacerbate deforestation. In this regard, Colombia should adopt binding obligations for REDD+ stakeholders, accompanied by meaningful monitoring system to address non-compliance. Strengthening accountability in this way would not only help deter misconduct but also increase the investment appeal of REDD+ initiatives, initiating a positive cycle of reduced deforestation driven by improved credibility in carbon offset mechanisms (Global Financial Integrity et al., 2025).

6.2.4 Social, Human Rights, and Community Participation Challenges

Broader human rights and social risks, particularly those affecting project developers and local communities living in project areas, should also be considered key factors influencing the limited effectiveness of deforestation reduction observed in this study. Colombia has been ranked among the most dangerous countries for environmental leaders according to the Global Witness index (Global Financial Integrity et al., 2025). Even within the Central and South American context, as observed in this study, Colombia's score on social security from the Fragile States Index (FSI) has been identified as higher than the donor country average, indicating greater social fragility and governance challenges. These broader social insecurities have translated into practical constraints during project implementation. For instance, in the Pirá Paraná region, security concerns—along with the limited institutional capacity mentioned earlier—restricted access to project sites, forcing verifiers to rely on satellite data (Global Financial Integrity et al., 2025). This suggests that the Colombian government should establish stabilization or protection mechanisms for project developers and verifiers to enhance both the effectiveness of the policy and the legitimacy of the overall system.

Moreover, approximately 66 percent of Indigenous reserve areas, excluding national parks, are currently tied to REDD+ projects, and nearly 29 percent have already generated credits (Global Financial Integrity et al., 2025). Given the scale of these areas, it is essential to safeguard the rights of Indigenous peoples by ensuring meaningful consultation and transparent integration of local communities into REDD+ processes. Yet, such consultations are often inadequate, non-transparent, or bypassed altogether, undermining the principle of free, prior, and informed consent (FPIC) (Global Financial Integrity et al., 2025). Therefore, a mandatory and well-structured consultation process should be established to ensure that Indigenous communities are involved from the earliest stages of project design. Embedding this requirement in REDD+ governance would not only uphold FPIC standards but also integrate traditional knowledge and cultural values, thereby enhancing project effectiveness.

6.3 Limitations

This study provides valuable insights by showing that Colombia's carbon tax has had a limited quantitative effect and by contextualizing the possible reasons for this outcome, but its findings should be interpreted with caution. First, the available emissions data do not fully correspond to the specific fuels targeted by the carbon tax, due to limitations in data availability. Specifically, the analysis relies on CO_2 emissions excluding Land-Use and on CO_2 emissions from oil. Neither of these measures is perfectly aligned with the specific scope of Colombia's carbon tax, which applies to a defined subset of fuels. This imperfect match between the policy target and the available data may weaken the precision of the estimates and dilute the observable policy effect in the aggregate indicators. Likewise, the analysis of deforestation may be confounded by natural disturbances such as forest fires, pests, or storms. As a result, the measure may overstate or misclassify certain aspects of land-use dynamics, thereby introducing uncertainty into the interpretation of forest-related impacts.

Beyond these measurement issues, other potential confounding factors remain. Despite robustness tests, the study cannot fully account for spillover effects from the carbon tax and offsetting mechanism. Moreover, macroeconomic conditions, political developments, and other external factors during the evaluation period may have influenced both Colombia and the donor pool, introducing potential bias into the results. Likewise, as Bretschger and Grieg (2024) argue, some donor pool countries may have implemented policies similar to carbon taxes, even if they are not formally labeled as such. The presence of these comparable measures in the control units could reduce the policy contrast between Colombia and its synthetic counterpart, thereby diminishing the clarity of the estimated effect.

The study's temporal scope also poses limitations. Behavioral changes induced by carbon taxation, such as shifts in electricity consumption, take longer to appear due to the inelastic nature of energy demand in the short term and greater elasticity over the long term (Errendal et al., 2023). However, since the most recent data available only extend to 2023 (as of September 2025), the analysis remains limited in capturing longer-term post-treatment effects. In addition, this limited post-treatment period is particularly relevant given the recent policy revision of 2023, which reduced the allowable share of carbon offsets from 100 percent to 50 percent of tax liabilities. This revision is expected to affect both carbon emissions from taxed fossil fuels and deforestation. However, although this study uses the most recent dataset, it is unlikely that the full implications are yet observable, as the data cover only one year after the policy change, underscoring the need for future updates as more post-revision evidence becomes available.

Finally, although minimizing the Mean Squared Prediction Error (MSPE) during the pre-treatment period allows the synthetic counterpart to fit Colombia relatively well, some variables still show noticeable discrepancies. For instance, in certain specifications, the variable oil rent (% of GDP) exhibits a substantial gap from Colombia's actual trajectory even before the treatment period. This indicates that isolating the impact of the carbon tax cannot be perfectly achieved due to these discrepancies, making it difficult to attribute post-treatment outcomes solely to the policy and highlighting the methodological challenge of constructing an ideal counterfactual in the Synthetic Control Method.

Overall, while this study offers important insights into the impact of Colombia's hybrid carbon tax and identifies potential sources of policy ineffectiveness, its findings should be interpreted with caution. The imperfect alignment between available emissions data and the specific scope of the tax, as well as confounding factors such as natural disturbances, parallel policies in donor countries, and macroeconomic shifts, pose notable constraints. Additionally, the short post-treatment period restricts the ability to observe longer-term behavioral and environmental responses—particularly following the 2023 policy revision that reduced the allowable share of offsets. Finally, discrepancies in pre-treatment variable matching underscore the methodological challenges inherent in constructing an ideal synthetic control. These limitations emphasize the need for future research that incorporates more granular data, extended observation periods, and improvements in methodological precision.

VII. Conclusion

Colombia has pursued ambitious climate policies through the introduction, in 2017, of a carbon tax combined with a carbon crediting mechanism. This study evaluated the effectiveness of these measures using SCM, focusing on three indicators: (a) CO_2 emissions excluding Land-Use, (b) CO_2 emissions from oil consumption, and (c) Tree Cover Loss (%). The findings reveal that while CO_2 emissions initially declined following the introduction of the carbon tax, this effect was short-lived and reversed in the aftermath of the COVID-19 pandemic. Tree cover loss remained consistently higher than that of the synthetic counterfactual across the study period, with only partial convergence in the most recent years. These results indicate that, within the observed timeframe, the policy produced only modest gains in emissions reduction and forest conservation.

This study highlights two key factors that help explain the policy's limited effectiveness. First, the relatively low tax rate and broad exemptions—especially the exclusion of coal—were unlikely to have meaningfully shifted emissions trajectories. The post-2020 emissions rebound appears linked to the expansion of fossil fuel subsidies during the COVID-19 pandemic, while the drop in average carbon credit prices since 2021—below the carbon tax level—likely diluted the policy's price signals and weakened its overall impact. Second, persistent implementation challenges within the carbon crediting mechanism, particularly regarding deforestation, further undermined the policy's effectiveness. Despite the adoption of Resolution 1447, gaps in institutional oversight, misaligned stakeholder incentives, and the absence of enforceable safeguards heightened the risks of over-crediting and carbon leakage, likely reducing the mechanism's overall effectiveness. In addition, insufficient protections for verifiers and limited engagement of local communities appear to have constrained the effectiveness of REDD+ based offsets.

In summary, although Colombia's hybrid carbon pricing framework represents a regionally innovative effort to advance climate mitigation, it remains hindered by structural and implementation-related constraints, resulting in modest performance to date. Nevertheless, recent policy adjustments—including the phased extension of the carbon tax to coal beginning in 2025 and the introduction of a 50 percent cap on the use of offsets—signal a strategic effort to enhance policy credibility and environmental effectiveness. In light of these factors, further research examining how these policy changes influence Colombia's mitigation outcomes would be valuable.

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Annexes

A1. Internship Organization

The internship was undertaken at the Seoul School of Integrated Sciences & Technologies (aSSIST), a public institution of the Republic of Korea that has played a significant role in advancing research and education for sustainable development. aSSIST originated from the Institute for Industrial Policy Studies (IPS), a think tank established in 1993 with the approval of the Ministry of Commerce, Industry and Energy. IPS has carried out extensive research on global industrial policy, providing advisory services to governments and corporate strategy support, while developing a strong profile in areas such as national competitiveness, sustainable management, creating shared value, brand valuation, design management, and policy development. In 2004, IPS established aSSIST to expand its educational mission. Since then, the institution has introduced a range of academic programs, most notably its dual degree programs with Aalto University in Finland and Stony Brook University in New York, United States, which have become internationally recognized.

In 2024, aSSIST expanded its global presence by establishing the SDG Management School in Geneva, Switzerland. This initiative was driven by the recognition of the critical role of innovative leadership in achieving the United Nations Sustainable Development Goals (SDGs). The school was founded on the principle that education should not only convey the theoretical foundations of the SDGs but also equip students with the ability to apply these principles in real-world contexts, aiming to cultivate leaders capable of guiding both corporate and societal transformations toward sustainability. As an original UNITAR-certified institution, the SDG Management School ensures that its programs meet the highest standards of education in sustainable development. Furthermore, through its global alliance network with leading universities and partnerships with international organizations, leaders, and industry experts, the institution provides opportunities for academic exchange, collaborative research, and professional engagement.

A2. Tasks and Outputs

The internship was conducted in a hybrid format with both aSSIST and the SDG Management School, combining remote tasks with on-site activities at the SDG Solution Space in Geneva. This hybrid arrangement ensured the successful completion of the internship while maintaining full commitment to the master's program.

Specifically, during the internship at aSSIST, the primary responsibility was to support the establishment and early operations of the newly founded SDG Management School in Geneva. This role involved serving as a liaison between the Korean headquarters of aSSIST and the SDG Management school, as well as maintaining close communication with UNITAR. By facilitating these interactions, the internship contributed to strengthening the institutional partnership and ensuring smooth coordination across different time zones and organizational cultures. In addition to the bridging role, administrative assistance was provided to both aSSIST and the SDG Management School, including the preparation of internal documents, support for coordination meetings, and assistance with event organization and logistics in Geneva, which has been crucial particuarly to the early-stage functioning of the institution.

Another central task was the contribution to research on case studies of universities integrating SDGs into higher education. This entailed an extensive review of more than 60 sustainability reports and relevant course materials from over 20 universities in Europe, the United States, and Asia, examining how these institutions embedded the SDGs in both their curricula and their administrative frameworks. Through this comparative analysis, patterns and best practices were identified, such as the incorporation of SDGs into academic programs, campus sustainability initiatives, operations, administration, finance and governance structures. Based on this analysis, the deliverables were to report a structured comparative matrix summarizing practices across the reviewed universities, as well as a set of recommendations identifying transferable strategies for curriculum development, campus operations, and governance. These outputs were subsequently shared with the aSSIST global cooperation team to inform institutional planning, serving as concrete inputs for the SDG Management School's program design.

Throughout this internship, the work directly addressed sustainability issues linked to multiple SDGs. Specifically, by serving as a bridge among aSSIST, the SDG Management School, and UNITAR, the internship contributed to SDG 17 (Partnerships for the Goals). Moreover, by analyzing how higher education institutions integrated sustainability into their core functions, the internship aligned with SDG 4 (Quality Education) and SDG 13 (Climate Action), thereby situating its outcomes within the broader global effort to advance sustainable development. In this way, the internship not only produced tangible outputs but also reinforced the shared commitment to achieving the SDGs.

A3. Personal reflection on the internship

The internship represented both a timely opportunity and a meaningful professional experience, particularly given the unique position of being a Korean student studying in Geneva. Strengthening communication channels between the two institutional branches was an important and memorable experience for me, particularly because the institution was in its formative stage, which allowed me to directly observe how my contributions influenced that progress. Although time differences occasionally required participation in online meetings at very early hours, the organization's flexibility in providing hybrid work options allowed for the simultaneous pursuit of academic responsibilities and professional contributions. This supportive arrangement was highly appreciated and enabled sustained engagement despite potential logistical challenges.

Beyond these bridging roles, the research assignment, particularly the review of sustainability strategies across universities worldwide, offered valuable insights into the diverse ways higher education institutions are engaging with the SDGs. Through this assignment, it became clear that while some universities have already made substantial progress in integrating sustainability into education, infrastructure, and governance, others remain at much earlier stages of this transformation. Notably, compared to European institutions, even leading Korean universities are only beginning to develop sustainability reports and related initiatives, which was unexpected and encouraged me to help aSSIST to highlight these gaps and accelerate the pace of institutional change in Korea. Moreover, observing initiatives ranging from curriculum reform to campus-level measures such as waste reduction and sustainable mobility (e.g., cycling facilities) reinforced the understanding that all higher institutions, not only governments or corporations, must actively contribute to sustainable development. This realization expanded the perception of universities beyond their traditional role as educational providers to that of active participants in societal transformation.

Overall, the internship provided practical experience at the intersection of research, education, and policy, while also underscoring the broader significance of institutional engagement in sustainability. Professionally, it enhanced cross-cultural communication skills, strengthened the ability to analyze complex institutional practices, and deepened the understanding of how the SDGs can be operationalized within higher education. At the same time, challenges were encountered, including the difficulty of balancing time zone differences, the limitations of hybrid work in fostering deeper interpersonal connections, and the constraints of contributing to an institution still in the process of formalizing its structures. These challenges, however, also offered valuable lessons in adaptability and resilience, further enriching the overall learning outcome of the internship. Taken together, the experience is expected to provide lasting value for both future academic research and professional roles in international organizations.