Are Carbon Credit Projects a Reliable Vehicle for Carbon Emission Reduction? Evidence from Geo-data

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Abstract

This paper investigates the voluntary carbon offset market and examines the effect of carbon offset projects on the reductions of deforestation rates. I employ a difference-in-differences (DID) approach within a regression discontinuity design (RDD) framework, distinguishing control and treatment regions based on proximity to project boundaries. Preliminary findings indicate an approximately 1.1% decrease in deforestation rates post-project initiation. Yet, potential methodological concerns necessitate furthur investigations in future studies.

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I. Introduction

In recent years, there has been a growing emphasis on environmental sustainability and the need to mitigate climate change through various means. Carbon offset program is one of the efforts, which enable individuals and businesses to counterbalance their carbon emissions by financially supporting projects that mitigate or eliminate an equal amount of greenhouse gases from the environment. According to Morgan Stanley (2023), the voluntary carbon offset market is expected to grow from $2 billion in 2020 to around $250 billion by 2050. However, many concerns have emerged regarding the integrity of carbon offset markets, particularly with respect to fraudulent practices.[1]

This paper investigates the voluntary carbon offset market and examines the effect of carbon offset projects on the reductions of deforestation rates. As an emerging market, voluntary carbon offsets have attracted corporate companies and individuals seeking ways to neutralize their carbon footprints. Organizers of carbon offset projects initiate and manage interventions aimed at reducing or eliminating greenhouse gas emissions. A significant faction of these interventions involves REDD+ projects (Reducing Emissions from Deforestation and Forest Degradation). REDD+ projects focus on forest conservation and the potential of such conservation efforts to reduce carbon emissions. These projects represent a tangible commitment to environmental preservation, and yet, their effectiveness has been a topic of debate. Some argue that these initiatives have played pivotal roles in forest conservation, while skeptics raise concerns over potential over-reporting or misrepresentations of their impacts.

To answer this question, this study employs a difference-in-differences (DID) methodology nested within a regression discontinuity design (RDD) framework. Specifically, I define the treatment area as the land within 2000 meters of the project boundary, and the control area as the land 2000 meters outside the project boundary. By harnessing a high-resolution annual forest loss dataset provided by Hansen, Potapov, Moore, Hancher,

[1] A relevant article from the Guardian can be found here.

Turubanova, Tyukavina, Thau, Stehman, Goetz, Loveland, Kommareddy, Egorov, Chini, Justice, and Townshend (2013), I exploit the staggered initiation of REDD+ projects across different time frames to examine the effect of these projects on the changes in forest coverage within project areas. I find these projects, on average, are effective in reducing the deforestation rate by approximately 1.1% over the next four years after the project starts. However, the validity of the findings, especially given the potential breach of the parallel trend assumption, implies the need for a more meticulous control group construction in future research. Further data acquisition, focusing on detailed land characteristics, will be useful for refining the analysis.

Related Literature. This research is primarily related to two strands of literature. First, the potential findings would speak to the growing concern about the carbon offset markets. Badgley, Freeman, Hamman, Haya, Trugman, Anderegg, and Cullenward (2022) investigate California's forest carbon offsets program and find that its design systematically over-credits carbon offsets, leading to the issuance of credits that do not reflect real climate benefits. West, Börner, Sills, and Kontoleon (2020) study the impacts of deforestation projects in the Brazilian Amazon and find that these projects' crediting baselines assumed higher deforestation than what was observed. West, Wunder, Sills, Börner, Rifai, Neidermeier, and Kontoleon (2023) study 27 forest conservation projects across six countries and find that most of these projects have not effectively reduced deforestation and those that did showed reductions significantly lower than claimed. Calel, Colmer, Dechezleprêtre, and Glachant (2021) find that a significant portion of carbon offsets in India was allocated to projects that would have proceeded regardless, leading to wasted resources and increased global carbon dioxide emissions. López-Vallejo (2021) discover that non-additionality, overestimated supply, and double counting are prominent quality concerns in Mexico's offset market. This paper contributes to the prior works by proposing a noval identification strategy and conducting a comprehensive study of all registered REDD+

projects. Leveraging the high-resolution annual forest loss dataset cross-referencing, this paper identifies the effect of REDD+ projects on the reduction of deforestation rates.

Second, in a broader view, this study relates to a growing literature of corporate greenwashing. Marquis, Toffel, and Zhou (2016) find that firms with greater environmental impact, especially those in countries with increased scrutiny and exposure to global norms, are less likely to engage in selective disclosure of benign environmental impacts. Ferrés and Marcet (2021) find that firms involved in price fixing schemes increase their CSR initiatives when they become targets of antitrust investigations. Li, Lou, and Zhang (2022) argue that commercial ties between ESG rating agencies and their clients lead to inflated ESG ratings. Lastly, Lyon and Montgomery (2015) synthesize the literature on greenwashing and emphasize the need for further research to identify, catalog, and model the mechanisms and impacts of various forms of misleading environmental communication. This paper contributes to the previous studies by systematically examining the carbon offset market and providing a novel angel to measure corporate greenwashing.

The remainder of this paper is structured as follows: Section II offers an overview of the carbon offset market. In Section III, I outlines data sources and provide pertinent summary statistics. Section IV demostrates the empirical methodology and presents the test results. Finally, Section VI concludes.

II. Carbon Offset Market Overview

This section provides the institutional background of the carbon offset market, a tool for reducing greenhouse gas emissions through carbon credit transactions. The market consists of two sectors: compliance and voluntary. This paper primarily focuses on the voluntary market.

A. Compliance Carbon Offset Market

The compliance market is part of a regulatory system, often a cap-and-trade system. These systems set a cap on total emissions and issue a limited number of emission allowances that can be bought, sold, and traded by companies. If a company emits more than its allocated allowances, it must purchase more allowances or offset credits to comply with the regulations. These purchases often happen in organized exchanges and are tracked by regulatory bodies. Over time, the cap is gradually lowered, reducing the total amount of emissions.

B. Voluntary Carbon Offset Market

In voluntary carbon market, carbon offset is a voluntary mechanism designed to mitigate greenhouse gas emissions by investing in projects that offset or reduce carbon emissions. Carbon credits are purchased as units of carbon dioxide removed from the atmosphere or prevented from being released. Carbon offset transactions are tracked by independent registries. There are four major registries — American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard, and Verra (VCS). They claim to provide a transparent system for tracking and verifying the issuance, ownership, and retirement of carbon offset credits. The registries require projects to undergo a rigorous process of measurement, monitoring, and third-party verification to ensure the credibility and accuracy of carbon offsets. Panel A of Figure 1 shows the amount of issuance and retirements of carbon credits over time. There are 287 million carbon credits issued in 2022, while 146 million retired.

Projects that generate carbon credits have many categories, such as renewable energy, energy efficiency, and forestry or land-use changes. Given the vast disparities in methodologies and impacts among various carbon credit projects, this paper narrows its lens to primarily explore REDD+ projects. Panel B of Figure 1 shows the amount of carbon offsets retired in each year by a few top project types. Among all project types, REDD+ projects stand out, accounting for the largest share of retired carbon credits, further justifying this paper's emphasis on them.

REDD+ Projects. REDD stands for "Reducing Emissions from Deforestation and Forest Degradation," with the 'plus' encompassing conservation, sustainable forest management, and enhancement of forest carbon stocks. Given the threats to tropical forests from various activities, REDD+ projects are mostly implemented in these regions, especially in developing nations. They provide financial incentives to landowners to maintain their forests rather than converting them for other uses. The emission reductions from these projects, representing carbon that would have been released if the forest was destroyed, are quantified into tradable carbon credits. The number of credits is determined through a methodology that involve counterfactual baseline emission calculations — representing emissions that would have occurred in the absence of the REDD+ project — and the actual emissions observed after project implementation. The difference between the two provides the net carbon emissions mitigated by the project.

III. Data and Summary Statistics

In this section, I introduce the data sources that I use for my studies and show the summary statistics.

A. Carbon Offset Project Data

This study utilize publicly available carbon offset data from four main carbon offset registries — American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard, and Verra (VCS) — in the United States. They keep track of carbon credit projects and cover most of the projects globallly. One can find detailed documents for each registered project on the registry's official website. These four registries generate almost all of the world's voluntary market offsets and provide valuable insights into carbon offset projects, project developers, and the issuance and retirement of various types of carbon credits.

Issuance and Retirement. I use the Voluntary Registry Offsets Database from So, Haya, and Elias' (2023) Berkeley Carbon Trading Project. So, Haya, and Elias (2023) collect and organize the cross-sectional project information, such as project ID, credit issuance, credit retirement, reported emission reduction, location, project start date, and etc. The dataset contains all carbon offset projects listed globally by four major voluntary offset project registries. As mentioned previously, Figure 1 provides the amount of carbon credit issuance and retirement over the year.

Project Area. The official public registry website provides detailed information for each project, most of the times including a KML file detailing the border of the project. I scrape the project description file for each REDD+ project in the registry. I collect all registered REDD+ projects that are started between 2005 and 2018. As I provide more details about the forest data later, I choose 2005 and 2018 so that my annual forest coverage data can have at least four years of both pre- and post-treatment periods.[2] I drop the projects that are too small or didn't provide project area data. In total, I collect 68 projects from all over the world. Figure 2 shows the countries that the projects are implemented. The darker the color, the more projects are implemented in this country. Brazil has the most REDD+ projects implemented (22 of them). Panel A of Figure 3 is a satellite image that shows the border of a project in Cambodia, called REDD in Keo Seima wildlife sanctuary. Figure IA.1 provides details for another project in Congo, called North Pikounda REDD+.

Panel A of Tabel 1 provides the summary statistics on the project level. We can see that 75% of the projects started between 2010 and 2014. The average area is 207,486 hectares. The average estimated annual emission reduction is 893,909 tonnes of CO_2e.

[2]There are only 5 projects started either before 2005 or after 2018.

Corporate Buyers. In the public registry data, approximately 50% of the retirement transactions also provides an one-sentence summary of the retirement details in the notes section. Using textual analysis, I extract the corporate buyers of corresponding carbon offset transaction. Figure 4 shows 20 companies that heavily involves in purchasing the carbon credits. The circles are sized by the amount of carbon credits retired by corresponding company. Some of the big corporate buyers are Shell, Delta, Disney, and Volkswagen.

B. Forest Loss Data

I utilize Global Forest Change data provided in the study by Hansen et al. (2013), which examines global forest changes using time-series Landsat images. The data covers the entire globe and has a resolution of squares approximately 30 meters wide at the equator. In my research, I focus on the tree canopy cover for the year 2000 dataset and the year of gross forest cover loss event dataset.

Tree canopy cover for year 2000 dataset. This dataset captures tree cover in 2000, detailing canopy closure for all vegetation taller than 5 meters. This dataset is represented as a percentage for each grid cell, indicating the proportion of canopy cover.

Year of gross forest cover loss event dataset. This dataset provides information on forest loss from the year 2000 to 2022. Specifically, it captures instances when forest areas underwent significant changes, transitioning from a forested to a non-forested state. The data is encoded in a manner where a value either signifies no loss, or it represents the particular year between 2001 and 2022 when the loss predominantly occurred.

Using two datasets above, I am able to observe the forest coverage for year 2000 and pinpoint the year of forest loss for roughly every 30x30 meters of the earth's surface. Subsequently, I construct a panel dataset for areas measuring 600x600 meters. I refer to each of these 600x600 meter sqaures as a land unit. Panel B of Table 1 offers summary statistics at the land unit level. Land units in the control (treatment) group have average forest coverage of 68.99% (80.27%) in the year prior to the project implementation.

IV. Empirical Methodology and Results

In this section, I first outline the development of research questions and related hypotheses. Next, I present the step-by-step empirical design and clarify the validity of the construction of each test.

A. Hypothesis Development

The effectiveness of carbon offset projects stands as a pivotal inquiry in the arena of environmental economics and corporate responsibility. On one hand, rising concerns about global warming have driven many companies to adopt environmentally responsible practices. One popular strategy involves purchasing carbon credits generated by carbon credit projects, under the belief that these efforts genuinely reduce carbon emissions. In acquiring these offsets, companies not only demonstrate their commitment to the environment but also aim to enhance their *green* reputation. This widespread corporate behavior indicates a general consensus regarding the positive impact of carbon offsets. However, skepticism exists. Several media outlets have raised concerns, suggesting that there exists carbon offsets that lack additionality, are subject to double-counting, or are non-existent.[3] These critiques further highlight the potential for firms that may overlook due diligence, leading them to invest in questionable carbon offsets.

Despite the contention, limited research has systematically investigated the carbon offset market to provide a rigorous measure of the effectiveness of the credits. To bridge this gap, this paper constructs an comprehensive dataset encompassing all publicly registered

[3] Relevant Bloomberg articles can be found here and here.

REDD+ projects. With granular annual forest coverage data, I examnie the real-world effects of these carbon offset projects. Since REDD+ projects' primary objective is forest preservation, it is crucial to determine if forests within these project areas truly remain protected. Considering the voiced concerns about the carbon offset market, the null hypothesis is:

H.0 *Carbon offset projects have no effect on the deforestation rates within their areas.*

On the other hand, given the significant corporate investment in carbon offsets, the alternative hypothesis suggests:

H.1 *Carbon offset projects lead to a significant reduction in deforestation rates within their areas.*

B. Empirical Design

To investigate the effect of carbon offset projects on deforestation rates within their designated areas, I employ a difference-in-differences (DID) methodology, nested within a regression discontinuity design (RDD) framework. Aligning with the RDD approach, I demarcate both control and treatment regions in proximity to the project boundaries. Specifically, the control region covers land located 2000 meters outside the project boundary, while the treatment region spans land 2000 meters within the boundary. Panel B of Figure 3 provides a visual representation of these control and treatment zones for a sample project. Within these delineated areas, I segment the land into units, each measuring 600x600 meters. Notably, each of these units comprises 20 squares of 30x30 meters from the Hansen et al. (2013) dataset. This is further depicted in Panel C of Figure 3. The basic regression I estimate is as follows:

$$ForestCoverage_{ipt} = \beta \left(Treat_{ip} \times Post_{tp}\right) + Distance_{ip} + \alpha_{ip} + \delta_{tp} + \epsilon_{ipt}, \quad (1)$$

where the dependent variable $ForestCoverage_{ipt}$ is the percentage of forest in land unit i in project p in year t. The main explanatory variable $Treat_{ip} \times Post_{tp}$ takes the value of 1 for the four years following a land unit i is preserved by a project p, and a value of 0 in the four years prior to a project implementation. I implement the regression discontinuity approach, by adding $Distance_{ip}$ as a control variable. It measures the closest distance between land unit i and the area of project p in terms of meters.

This identification strategy allows me to employ a difference-in-differences methodology that exploits the staggered implementation of REDD+ projects over time. The first difference is the change in forest coverage before and after the start of a REDD+ project. The implicit control group at time t consists of land units located in areas without a REDD+ project. The change in forest coverage within this control group is the second difference captured in my tests. The effect of REDD+ projects on land-unit-level forest coverage is estimated as the difference in those two differences. The regression discontinuity approach provides evidence that the test is not simply capturing any effect driven by the characteristics of the land which is far away from the project area, which coincides with but is unrelated to the the implementation of REDD+ projects.

C. Empirical Results

To test the hypotheses, I conduct the analysis with two different event windows and report the results in Table 2. I examine whether the forest coverage changes in REDD+ project areas after the projects are implemented. To do so, I employ a DID methodology within an RDD framework. I run the regression specified in Equation (1) both in a four-year window and in an eight-year window. In the eight-year window regression, there are fewer projects involved in the sample due to longer pre- and post-event periods.

Table 2 reports the results from estimating Equation (1) using forest coverage as the dependent variable. The only difference between the two columns is the length of pre- and post-event periods. In both regressions, the coefficient associated with the treatment effect is positive and significant at $p < 0.05$.

In terms of economic magnitude, the results indicate that the implementation of a REDD+ project increases the reduction in deforestation rate by approximately 1.1% (based on Column 1). The finding indicates that a REDD+ project slows down the decline of forest coverage in the project area, suggesting that carbon offset projects are, on average, effective means of carbon emission reduction.

However, several concerns persist. While the test presents a positive and statistically significant outcome, the alignment between self-reported emission reductions from these projects and the test results remains uncertain. Over-reporting the impact on deforestation reduction could be a potential issue. This is one of the next steps where this research project is heading to. Furthermore, the validity of my empirical findings hinges on the parallel trend assumption being satisfied. Unfortunately, Figure 5 indicates that this assumption might not hold in this context. This implies the need for a more meticulous construction of the control group. More data collection regarding land characteristics is imperative to facilitate a more precise matching between control and treated land units. Third, from reading the trends of forest coverage in the pre-treatment periods, 5 shows the land units in the project area are already decreasing in a slower rate than units outside the project area. This implies the deliberate chioce of project area by the project organizers.

V. Conclusion

The rigorous examination of the carbon offset market is of great importance, particularly given the rising concerns and skepticism and limited existing research on its impact. This study posed a fundamental question: do carbon offset projects significantly slow down the deforestation rates within their designated areas? To address this, I employ a difference-in-differences (DID) approach within a regression discontinuity design (RDD) framework, distinguishing control and treatment regions based on proximity to project boundaries. I find that the implementation of REDD+ projects indeed leads to a reduction in deforestation rates. However, it's worth noting the study's inherent limitations. The validity of the findings, especially given the potential breach of the parallel trend assumption, underscores the need for a more meticulous control group construction in future research. Further data acquisition, focusing on detailed land characteristics, will be also useful for refining the analysis.

Looking ahead, future research should address several critical dimensions within the carbon offset market. Firstly, a pressing concern lies in whether the self-reported emission reductions by projects align with the true deforestation reduction found in this study's results. This would provide insights into the accuracy and credibility of project reporting metrics. It can also provide policy implications and enforce stricter reporting protocols. Additionally, a granular investigation into the heterogeneous effects across different projects is needed. Such an approach would pinpoint projects that, despite their claims, fail to yield significant positive effects. Following this, one can ask an intriguing economic question: are carbon offsets from less effective projects traded at discounted rates? Lastly, understanding the identities, characteristics, and decision-making processes of the corporate entities that purchase these offsets is essential. Unraveling these strands will not only enrich our understanding of the carbon offset market dynamics, but could also catalyze tangible shifts in market practices and corporate behaviors.

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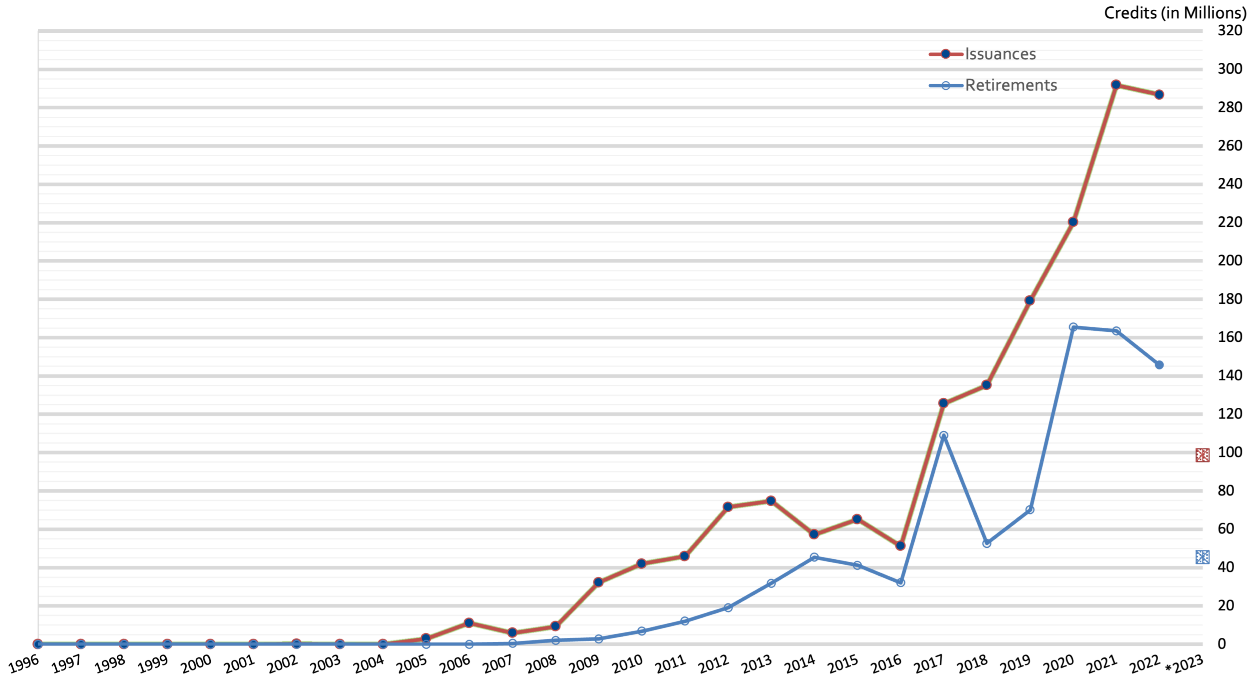
Figure 1: Carbon Credits Issuance and Retirement

This figure shows the amount of carbon offsets issued and retired by year and by type. A carbon offset is retired when it has been purchased by a buyer. Panel A contrasts the amount of issuance and retirements over time. Panel B shows the amount of carbon offsets retired in each year by a few top project types. The data are sourced from So, Haya, and Elias's Berkeley Carbon Trading Project.

Panel A: Credits Issued and Retired Over Time



Panel B: Most Retired Types by Retirement Year

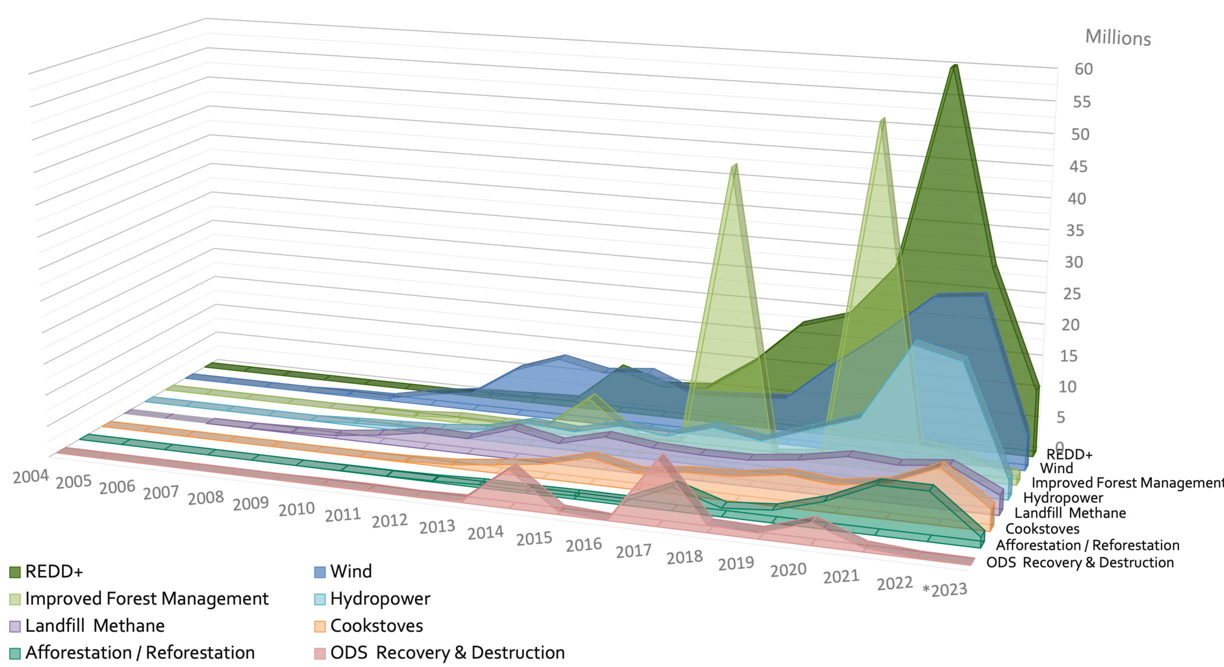


Figure 2: Map of Countries that Implemented Carbon Offset Projects

This figure plots the countries that implemented REDD+ projects between 2005 and 2018. The darker the color, the more projects have been implemented in the corresponding country. There are 68 projects in total. Project information are collected from carbon offset public registry.

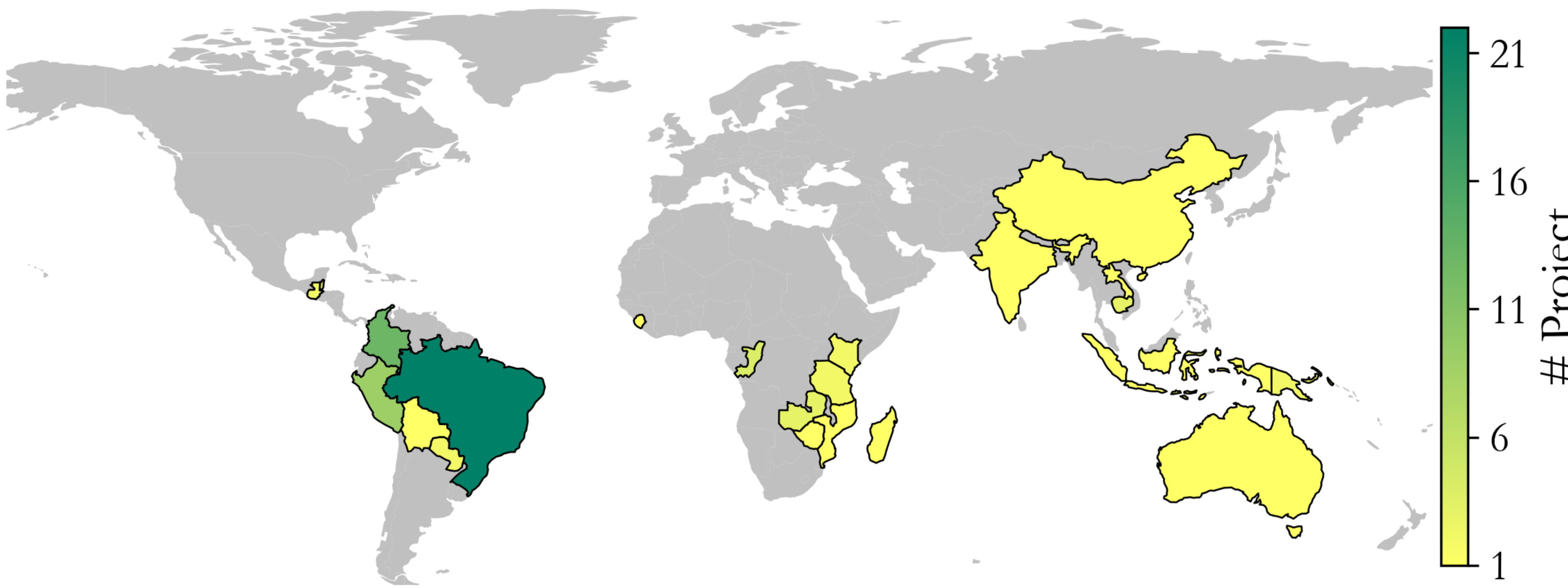
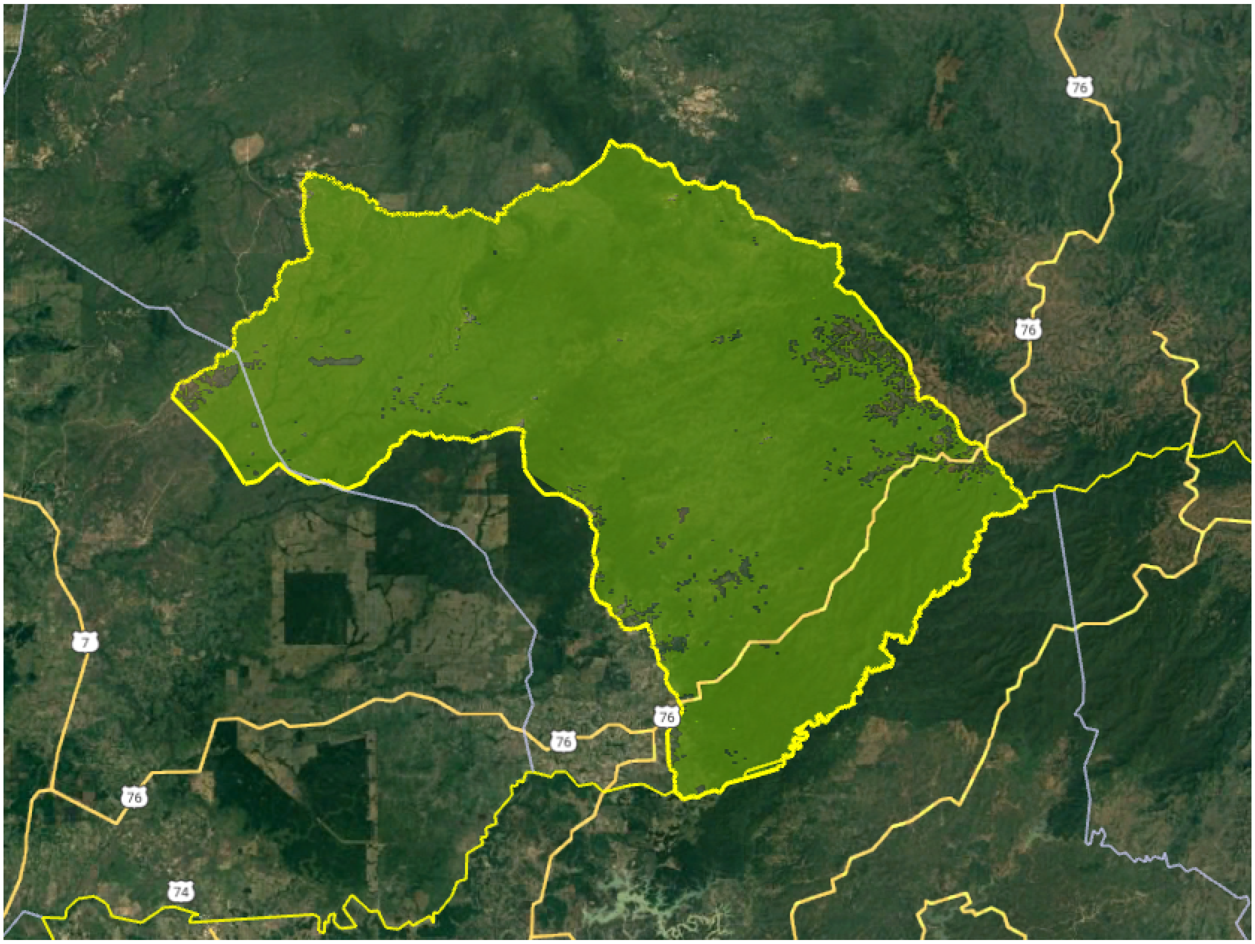


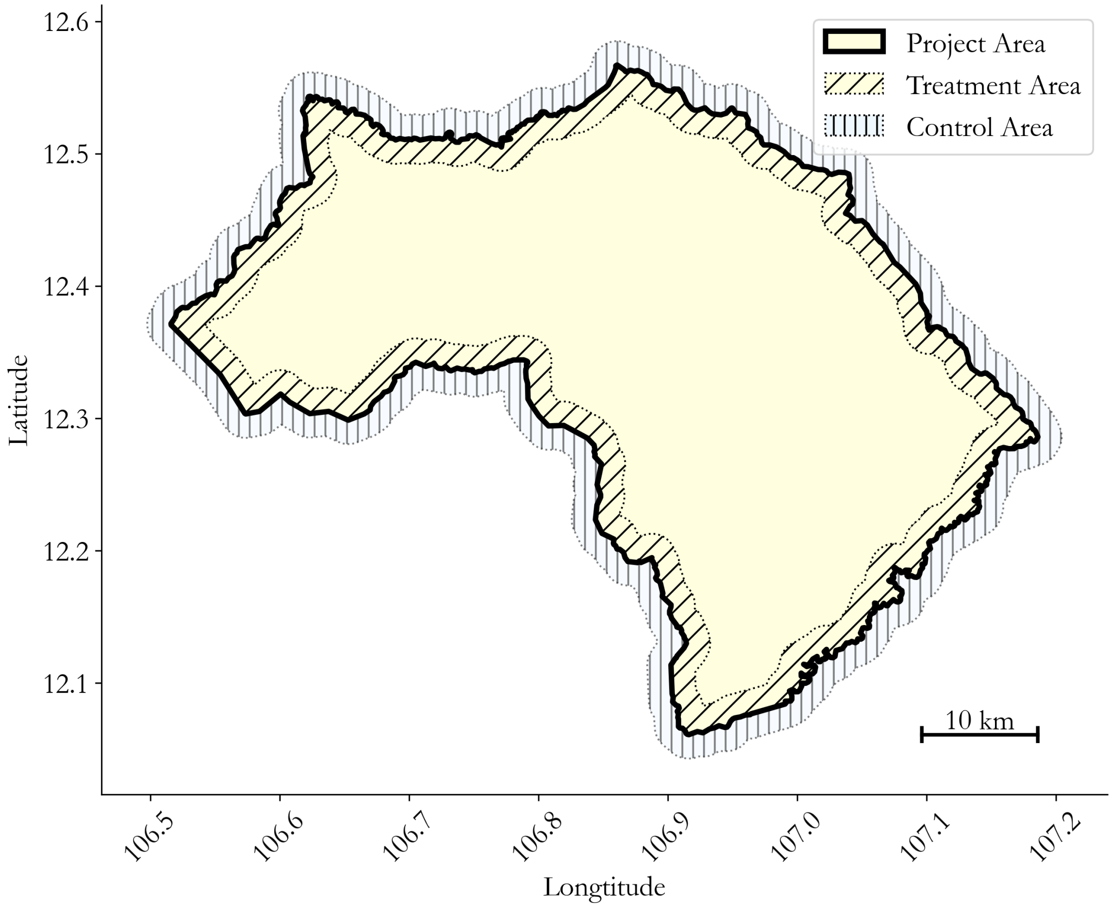
Figure 3: Project Area

This figure demostrates the project area of a sample project. The project is named as REDD Project in the Keo Seima Wildlife Sanctuary and is implemented in Cambodia. Panel A shows a satellite image of the project area. Panel B shows the control and group area. The treatment area is defined as the land within 2000 meters of the project boundary, and the control area as the land 2000 meters outside the project boundary. Panel C shows the land units inside either the control or treated area. Each land unit is a 600x600 meter sqaure.

Panel A: Satellite Image



Panel B: Control and Treatment Area



Panel C: Land Units

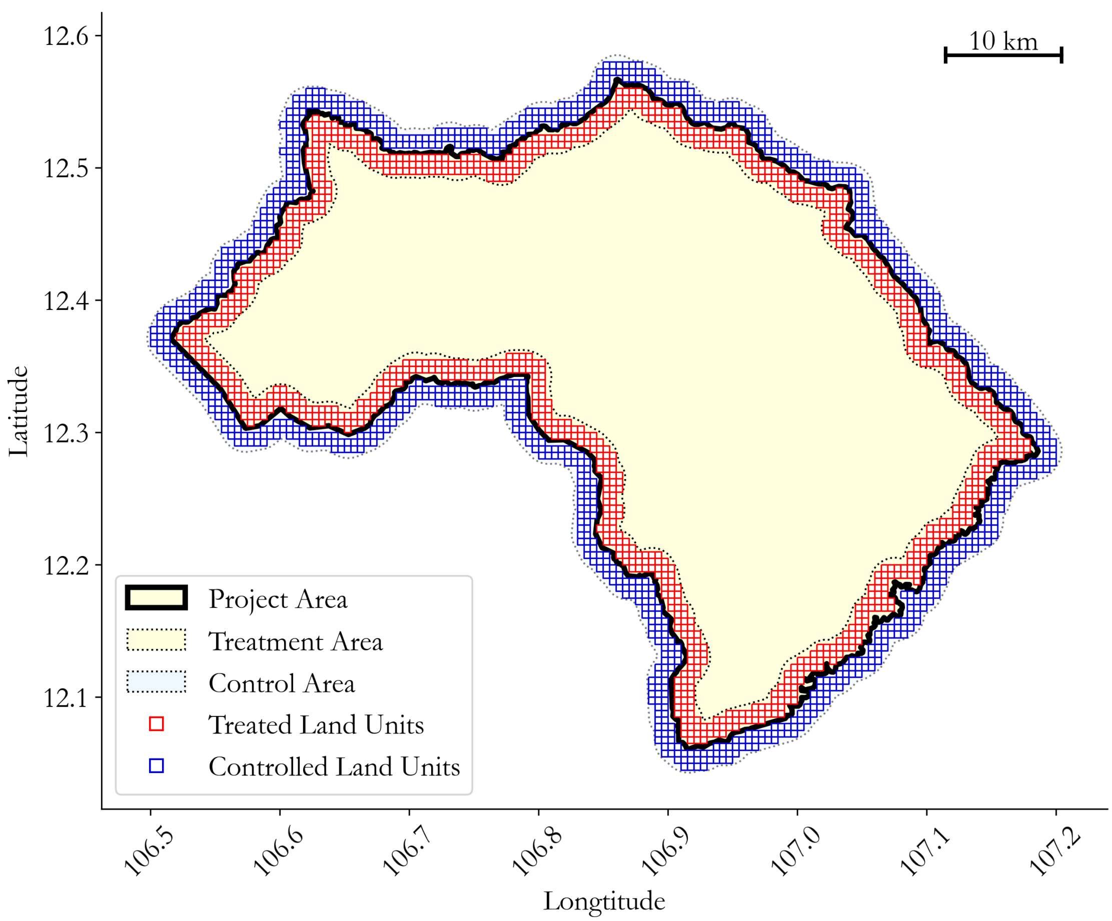


Figure 4: 20 Big Corporate Buyers of Carbon Credits

This figure displays the 20 companies with significant involvement in purchasing carbon credits. Circle sizes correspond to the volume of carbon credits each company has retired. The sample data include all transactions up to May 2023 from four primary registries: the American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard, and Verra (VCS). Note that these 20 companies are not necessarily the top 20 corporate buyers.

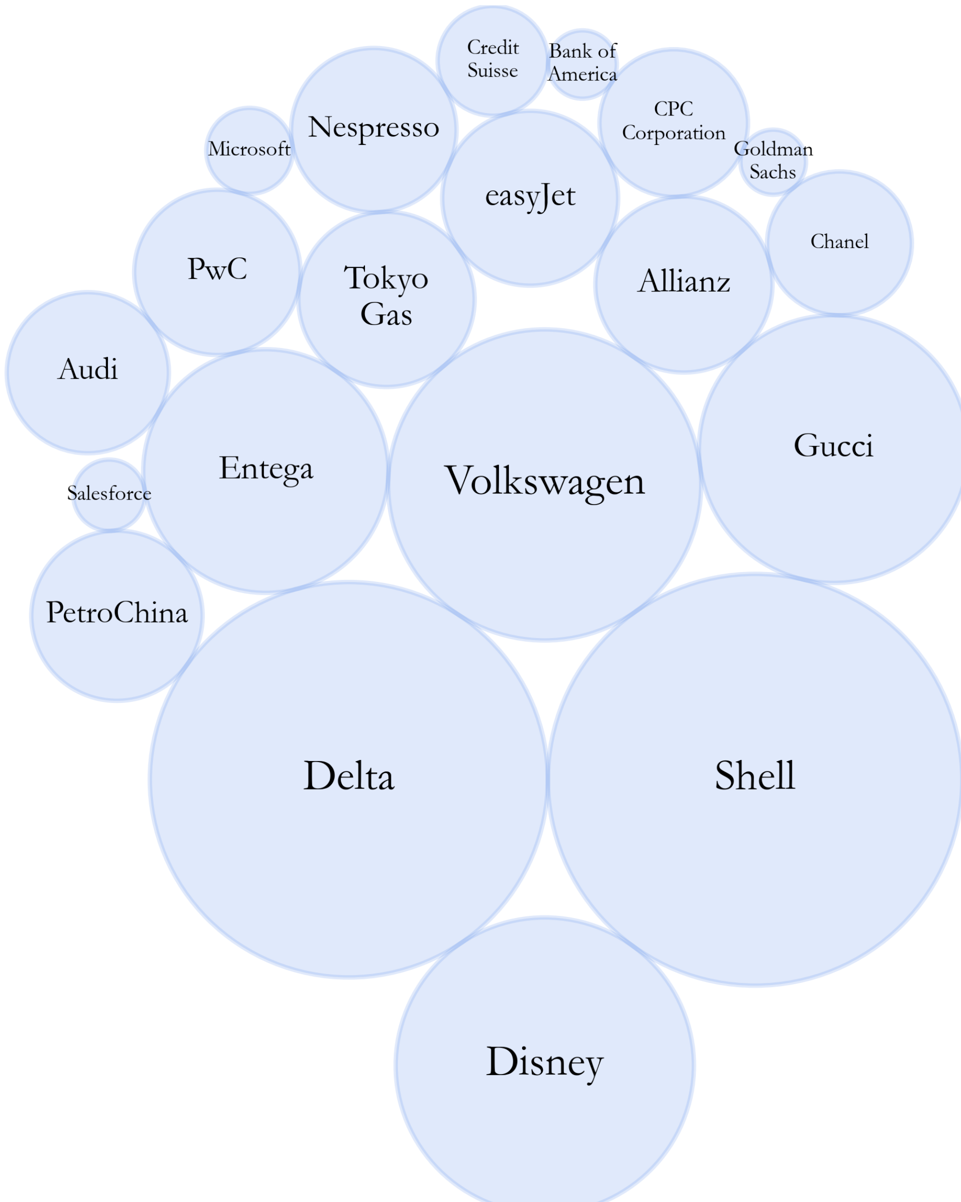
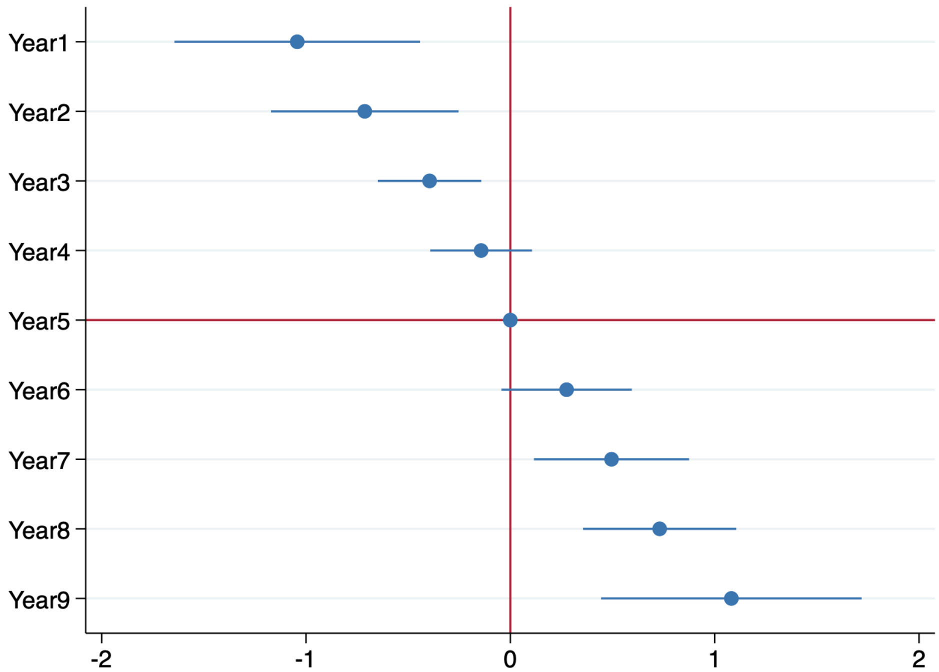


Figure 5: Effect of REDD+ Projects on Forest Coverage

This figure plots the coefficient on $Treat \times Post$ using the $ForestCoverage$ as the dependent variable around the start of REDD+ projects. It shows the effect of carbon offset projects on the reductions of deforestation rates. The error bars represent 95% confidence intervals based on standard errors double clustered by year and project.

Panel A: 4 Year Window



Panel B: 8 Year Window

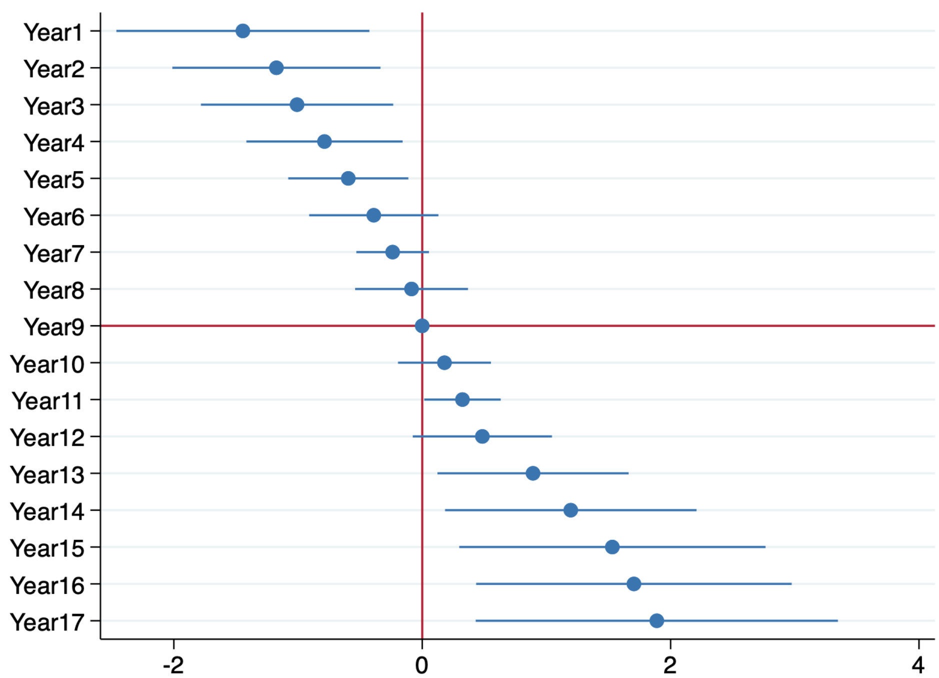


Table 1: Summary Statistics

This table presents summary statistics for various metrics. Panel A provides statistics at the project level, whereas Panel B details metrics at the land unit level. In Panel A, the project's area is quantified in hectares. The forest coverage is calculated as a percentage (ranging from 0 to 1) and represents the coverage in the year preceding the project's implementation ($t-1$). Emission reductions refer to the estimated annual emission reductions reported by the project, denominated in tonnes of CO_2e. In Panel B, each land unit is a square which has the width of 0.005 degrees (approximately 600 meters). Distance is measured in meters. It represents the closest distance between the land unit and the project area. All forest coverage measures are calculated as a percentage (ranging from 0 to 1).

					Quartiles			
	Count	Mean	Std	Min	1st	2nd	3rd	Max
				Panel A: Project Basics				
Start Year	68	2012	3	2005	2010	2012	2014	2018
Area	68	207486	309476	3392	44211	99435	193175	1376474
Emission Reductions	68	893909	1524274	96	118862	304783	952861	7451846
				Panel B: Land Units				
Units in the control group								
Distance	103091	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forest Coverage (2000)	103091	70.67	36.09	0.00	28.78	94.74	98.73	100.0
Forest Coverage ($t-1$)	103091	68.99	36.55	0.00	26.86	92.60	98.44	100.0
Units in the treatment group								
Distance	74813	643.14	386.42	0.00	306.29	631.45	970.01	1588.72
Forest Coverage (2000)	74813	85.66	20.55	30.00	80.03	96.73	99.19	100.00
Forest Coverage ($t-1$)	74813	80.27	25.70	0.00	65.30	94.62	98.91	100.00

Table 2: Regression Result

This table examines the effect of REDD+ projects on the reductions of deforestation rates. I estimate the OLS regression of the form:

$$ForestCoverage_{ipt} = \beta \left(Treat_{ip} \times Post_{tp}\right) + \alpha_{ip} + \delta_{tp} + \epsilon_{ipt},$$

where the dependent variable $ForestCoverage_{ipt}$ is the percentage of forest in land unit i in project p in year t. The main explanatory variable $Treat_{ip} \times Post_{tp}$ takes the value of 1 for the four years (or eight years) following a land unit i is preserved by a project p, and a value of 0 in the four years prior to a project implementation. $Distance_{ip}$ is a control variable and measures the closest distance between land unit i and the area of project p in terms of meters. Fixed effects are indicated at bottom of each column. Standard errors are double clustered by year and project and reported in parentheses.

	4 Year Window	8 Year Window
	(1)	(2)
$Treat \times Post$	1.090***	1.626**
	(0.256)	(0.597)
Land Unit FE	✓	✓
Project-Year FE	✓	✓
Observations	1,601,136	1,816,178
R-squared	0.985	0.975

Standard errors double clustered by year and project
*** p<0.01, ** p<0.05, * p<0.1

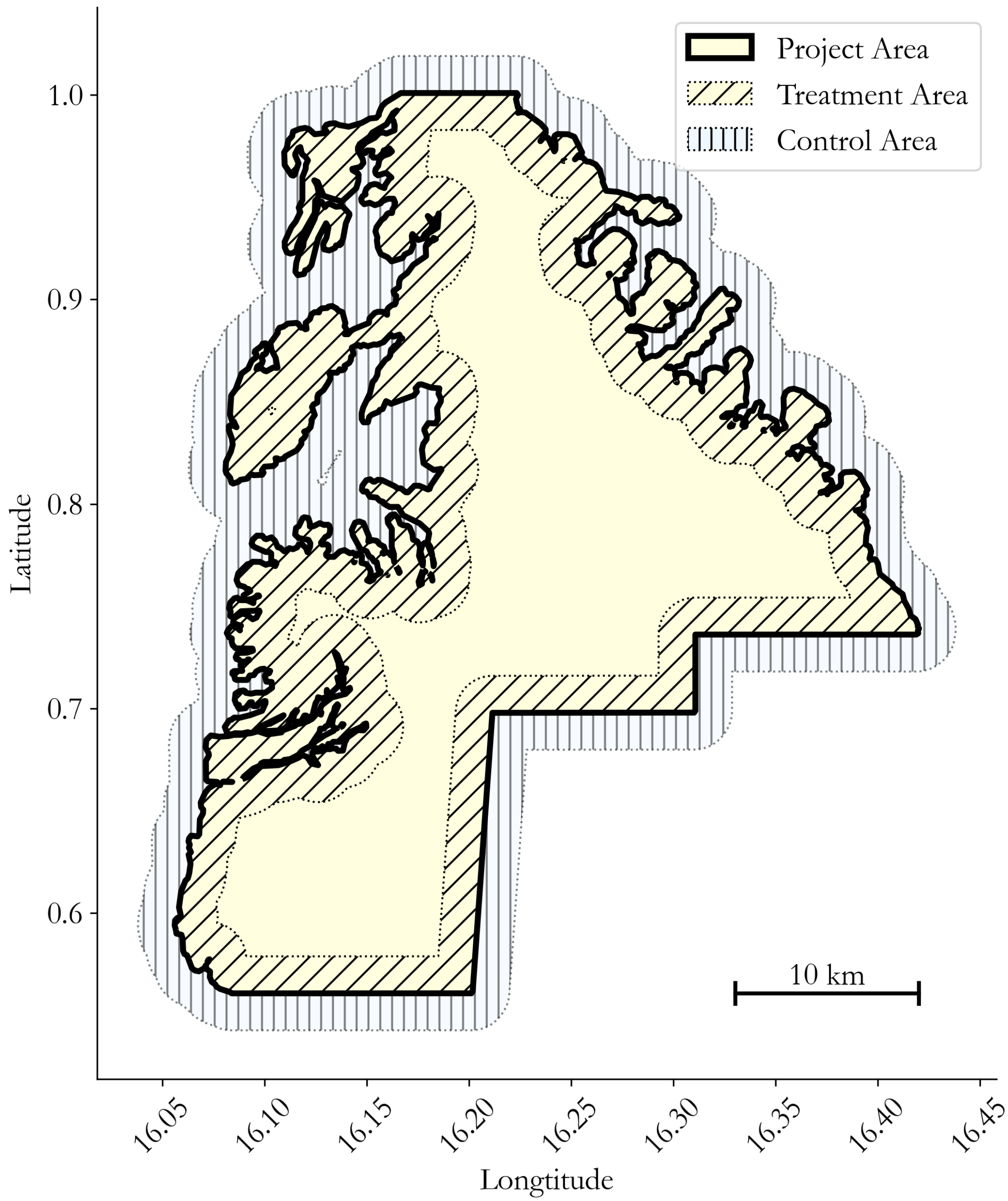
Internet Appendix for
"Are Carbon Credit Projects a Reliable Vehicle for Carbon Emission Reduction? Evidence from Geodata"

Figure IA.1: Project Area

This figure demostrates the project area of a sample project. The project is named as the North Pikounda REDD+ Project and is implemented in Congo. Panel A shows a satellite image of the project area. Panel B shows the control and group area. The treatment area is defined as the land within 2000 meters of the project boundary, and the control area as the land 2000 meters outside the project boundary. Panel C shows the land units inside either the control or treated area. Each land unit is a 600x600 meter sqaure.

Panel A: Satellite Image

Panel B: Control and Treatment Area



Panel C: Land Units