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Empirical analysis of the Voluntary Carbon Market

Impact of project characteristics on carbon credit projects

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A wish to make the voluntary carbon market’s uncertainties clear is what motivated the thesis. I would want to thank Professor Leif Kristoffer Sandal, my supervisor, for his direction and Professor Ivan Belik for his econometric approach guidance. Both of them have enhanced my research.

Abstract

In this thesis, I explore the dynamics and effectiveness of carbon offset projects within the Voluntary Carbon Market (VCM), examining how regional, technological, and economic factors influence the performance of these initiatives globally. The need for climate action is growing, thus understanding the nuances of carbon offset becomes important. This study delves into whether the effectiveness of carbon offset projects varies significantly across different regions, project scales, and the presence of carbon pricing mechanisms, translating these broad queries into a focused investigation. Through the formulation and testing of specific hypotheses, I analyse a dataset comprising information on over 7,466 carbon offset projects sourced from the Berkeley Voluntary Registry Offset Database.

The thesis goal is to estimate the quantitative impact of factors on the retirement rate of carbon credits, the effectiveness of projects. Firstly, I examine the effectiveness of carbon offset projects across various factors such as scales of projects, the location, and the used technology scope using comparative analysis. I then use econometric methods and measure its efficacy using regression methods like Beta, Tobit, and OLS regression models. The study results imply that small-scale and developed projects typically show greater effectiveness. Although the results are consistent across several model specifications, they highlight how complexly economic, technological, and environmental policy interact to determine how successful carbon offset projects are.

The results should not be interpreted as definitive evidence of causal relationships due to potential issues such as endogeneity and omitted variable. Instead, the findings offer a framework for understanding how various factors influence the effectiveness of carbon offset projects in the VCM. This thesis contributes to the broader field of environmental economics and policymaking for the VCM, especially as empirical investigations into the nuanced dynamics of carbon markets continue to evolve.

Contents

1. Introduction

The science is clear, we must reduce greenhouse gas emissions by 43% by 2030 to limit global warming to 1.5 C above pre-industrial levels (IPCC, 2022). The Voluntary Carbon Market (VCM) has become a significant participant in the effort to combat climate change by reducing greenhouse gas emissions (BCG, 2023). The involvement of this market in the sale of carbon credits highlights a dedication to sustainability led by companies that need to meet their sustainability goals. Carbon markets, by putting a price on carbon, push companies to use greener methods and technologies, which eventually lowers emissions and helps the fight against climate change (Streck, 2021). Nevertheless, the efficacy of this system, particularly with regards to the allocation of credit and retirement, continues to be a subject of ongoing debate (Filewod, Gsottbauer, & Macquarie, 2023).

Carbon markets consist primarily of two types: voluntary and compliance markets (UNDP, 2022). Governments create compliance markets to control and require companies in particular sectors to cut back on their emissions. To offset their emissions, businesses buy carbon credits, and noncompliance can result in fines or penalties (European Commission, 2024). Contrarily, companies are motivated to invest in the voluntary carbon market primarily for carbon management, market competitiveness, and alignment with company values (Lou, Hultman, Patwardhan, & Irving, 2023). They offset their carbon footprint for these reasons in ways that strike a balance between expense, public perception, and core company values.

Companies will need to do due diligence because there aren't any precise rules yet for determining which projects to finance. For businesses wishing to purchase carbon credits, this uncertainty makes decision-making difficult. Though there is a lack of actual data to support these choices, independent firms provide advice on credit purchases. Companies must navigate these choices based on the type of technology they wish to support and the geographical implications of their investments. They have to choose between projects that guarantee measurable carbon reductions and are shown to produce real environmental benefits and those that provide social benefits, such promoting economic growth in underdeveloped regions.

This gap in the literature and market guidance underscores the necessity for an analysis of the VCM's dynamics and outcomes. Although a few studies have begun to explore these aspects, comprehensive research on the effectiveness of various projects within the voluntary carbon market remains scarce. By examining the projects registered by the four largest registries in the Berkeley Voluntary Registry Offset Database, this thesis aims to shed light on the quantitative factors that contribute to the success of carbon offset initiatives. It will provide companies, policymakers, and stakeholders with deeper insights into which projects yield the highest effectiveness, guiding better-informed decisions in the rapidly evolving landscape of carbon markets.

My motivation for this study springs from a concern about the escalating impacts of climate change, coupled with an intense curiosity about the mechanisms through which we can mitigate these effects. As global temperatures rise and the consequences become more severe and visible, the urgency to find effective solutions has never been more critical. Voluntary Carbon Markets have emerged as a promising avenue through which emissions can be offset, but the variability in their effectiveness and the complexity of the market present significant challenges. The drive to explore these markets more deeply is fuelled by my desire to contribute to a more sustainable future and to deepen our understanding of how different factors influence the success of carbon offset projects within these markets.

Delving into this research, I was particularly drawn to the potential of VCMs to facilitate meaningful environmental benefits through projects that reduce or sequester carbon emissions. My academic background and personal interests in environmental science and economic models have equipped me with a unique perspective on the intersection of market-based solutions and environmental policy. Through this study, I aspire to deepen the understanding of the driving factors behind projects, aiming to enhance their reliability and efficacy in combating one of the most daunting challenges of our time: climate change.

This thesis also grapples with ethical and strategic dilemmas, as the results might inadvertently favor investments in more developed regions due to their apparent efficiency and proven success in emissions reductions. Such findings could skew investment priorities towards developed areas, potentially overshadowing the critical need for investments in less developed regions. These regions not only require financial inflows to spur growth and innovation but also play a role in the global strategy to combat climate change. Prioritizing investments based solely on efficiency metrics might undermine the broader goals of equity and sustainability in global climate action. This emphasizes the importance of a balanced approach in carbon credit investments, ensuring that support is extended universally to foster both proven results and equitable growth across diverse geographies.

1.1 Research question

Over the past few decades, the VCM has grown substantially as a wide range of organizations use carbon credits to offset their emissions and prove their dedication to sustainability (Streck, 2021). Despite the VCM's popularity, there is still little understanding of the effectiveness of credits (Filewod, Gsottbauer, & Macquarie, 2023). Therefore, the purpose of this research is to untangle the complexities of the VCM, focusing on the different aspects of carbon credit projects such as the geographical and sectoral differences in its performance, here effectiveness between retired credits and issued credits, and thus to add to the existing literature with in-depth market insights focusing on data driven insights.

The research by Fujii et al. (2024) highlights a significant gap in the literature concerning the analysis of the voluntary carbon market from a macro perspective, particularly regarding regional and technological trends. This lack of analysis limits understanding of the factors driving the effectiveness of carbon credit projects across different contexts. The key objective is to explore how different factors influence the effectiveness of carbon credits, with an emphasis on the correlation between issued and retired credits as indicators of project effectiveness. I will examine a database of voluntary carbon projects from four registers to identify factors to fill this knowledge gap. This research aims to inform the development of more effective and impactful initiatives that can support the global effort to reduce greenhouse gas emissions by identifying the elements that contribute to effective carbon offset projects.

The main research question of the thesis is formulated as follows:

"How do different factors such as scale of projects, geographic location, and sector-specific dynamics affect the effectiveness of carbon credit retirement within the Voluntary Carbon Market?"

1.2 Structure

The structure of this thesis is organized to ensure an exploration of the voluntary carbon market, focusing on the issuance and retirement of carbon credits across various factors. The thesis begins with an Introduction in Chapter 1, which sets the stage by articulating the main objective and defining the scope of the research. This chapter introduces the research question and outlines the rationale behind the study, establishing the need for an in-depth analysis of carbon credit dynamics within the VCM. It lays the groundwork for understanding the significance of these markets in the broader context of climate change mitigation. Chapter 2 serves as the literature review and hypothesis setup, focusing on existing research related to carbon markets, emphasizing studies on the VCM. This section explains the role of carbon markets in mitigating climate change, distinguishing between compliance and voluntary carbon markets. It also discusses the evolution of these markets and their critical role in global efforts to reduce greenhouse gas emissions. This chapter explores how voluntary carbon markets fit into the wider environmental policy landscape, identifying gaps in current research that the thesis aims to address. To gain a deeper understanding of the factors influencing the projects, hypotheses have been developed based on the literature review.

Chapter 3 covers the Experimental Setup, detailing the methodology, data collection, and analytical techniques employed to assess the effectiveness of the VCM. It explains the choice of database, the variables selected for analysis, and the statistical methods used to interpret the data. The Results are presented in Chapter 4, illustrating the patterns and trends identified in the data concerning the issuance and retirement of carbon credits across different regions and sectors. The Discussion in Chapter 5 delves deeply into the implications of the results. The results are discussed in this chapter within the larger frameworks of previously introduced theoretical works and literature. It discusses the study's shortcomings, highlights its contributions to the body of current knowledge, and recommends areas for more investigation.

The thesis concludes in Chapter 6 with a summary of the key results and a reflection on the study's impact on understanding the VCM. Additionally, the thesis includes a References section and an Appendix. The Appendix offer supporting materials that provide additional data and detailed tables that underpin the research findings. The structured approach ensures that each chapter builds upon the previous one, leading to a conclusion that ties back to the research question.

2. Background and literature review

The need for effective climate action grows as the planet experiences unprecedented changes in climate patterns, characterized by extreme weather, rising temperatures, and major ecological disruptions affecting every country on every continent (United Nations, 2024). This chapter delves into how voluntary carbon markets have become an element in the global strategy to reduce greenhouse gas emissions. It outlines the evolution of these markets, their operational dynamics, and their increasing significance in fostering corporate and individual actions towards achieving carbon neutrality. By examining the mechanisms through which VCMs operate and their influence on global carbon reduction efforts, this chapter sets the stage for a deeper understanding of their potential and challenges in contributing to climate goals by making hypotheses that will give new insight to the VCM.

2.1 Climate Change and the Voluntary Carbon Market

The threat of climate change casts a significant shadow over our planet, posing an unparalleled crisis with far-reaching consequences for natural systems, human well-being, and the global economy (IPCC, 2022). The global climate stability is being disturbed, characterized by changing patterns in temperature and rainfall. This disruption foreshadows grave repercussions, such as severe weather events, acute water scarcity, widespread wildfires, coastal inundation, arctic ice retreat, and the degradation of the Earth's biodiversity. The narrative of climate change revolves around the significant impact of human activities, particularly the use of fossil fuels which emit substantial quantities of greenhouse gases, primarily carbon dioxide (European Commission, 2024). The primary driver of global warming is the human-induced impact, a claim strongly backed by scientific consensus and emphasized by the Intergovernmental Panel on Climate Change's (IPCC) latest findings (IPCC, 2022). The widespread influence of these emissions on the Earth's atmosphere and biosphere establishes the need for urgent action to tackle what could be considered the most significant environmental challenge of the 21st century.

Facing the increasing climate emergency, countries worldwide have united under the guidance of the United Nations to establish a clear direction, as demonstrated by the momentous Paris Agreement of 2015 (Wongpiyabovorn, Plastina, & Crespi, 2023). The UNFCCC has established a significant agreement that represents a worldwide consensus among 200 countries to mitigate global warming and create a resilient, carbon-neutral future. The increasing focus on the climate agenda has also raised expectations regarding corporate governance, leading to policy, economic, and consumer pressures to make businesses responsible for their environmental effects (Ahonen, Kessler, Michaelowa, Espelage, & Hoch, 2022; Andonova & Sun, 2019). Amidst this changing environment, climate change is not only seen as a risk that needs to be dealt with, but also as a catalyst for significant change. This forces businesses of all types to integrate sustainability and climate-focused financing into the fundamental principles of their operations.

The paper by Battocletti, Enriques, & Romano (2023) discusses the dynamics within the Voluntary Carbon Market, focusing on the participation of historically large emitters, such as energy companies. These corporations, which have historically contributed significantly to greenhouse gas emissions, are now actively engaging in the VCM by funding carbon offset projects. This participation is particularly notable in developing countries, where a large amount of these projects is located. The authors argue that this trend not only helps mitigate the companies' carbon footprints but also serves an ethical role by shifting the burden of carbon offsetting to those historically responsible for large emissions. This mechanism aids in financing essential climate mitigation projects, which aligns with the broader goals of global climate agreements like the Paris Agreement

2.1.1 History of the Carbon Markets

The voluntary carbon market emerged as a response to growing global apprehensions regarding climate change and the pressing imperative to mitigate greenhouse gas emissions (Wadhwa, Nowak, & Behr, 2022). Defined as market-based platforms where carbon credits are traded voluntarily, these markets offer entities the opportunity to offset their greenhouse gas emissions by investing in environmental projects that reduce or sequester carbon emissions. Figure 1 shows the structure of the Voluntary Carbon Market showing the interplay between standards, project developers, and buyers of the credits that want to offset emissions.

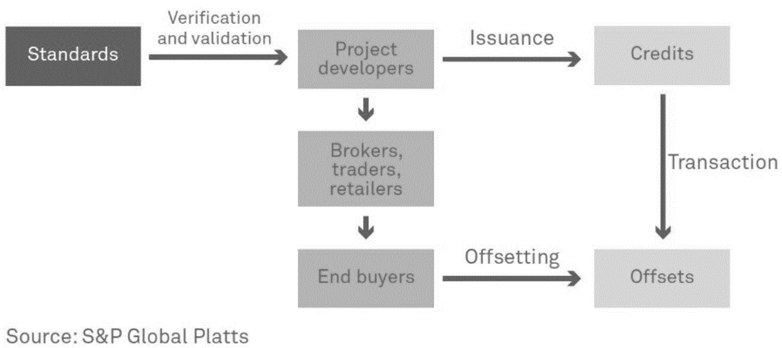


Figure 1 Structure of Voluntary Carbon Market (Favasuli & Sebastian, 2021).

The evolution of VCMs has been shaped by a complex interplay of environmental policies, corporate social responsibility initiatives, and market-driven forces (Climate Impact Partners, 2023). Historically, the establishment of the Kyoto Protocol in 1997 marked a significant milestone, introducing mechanisms like the Clean Development Mechanism (CDM), which laid the groundwork for carbon trading (Spilker & Nugent, 2022). However, it was the recognition of climate change's urgency, coupled with governmental inaction, that spurred the growth of VCM. Entities, driven by a commitment to sustainability and under increased scrutiny from stakeholders, turned to VCMs to demonstrate climate action. These markets provided platforms for companies or individuals to purchase carbon credits on a voluntary basis, rather than as mandated by regulations. The first VCM, the Chicago Climate Exchange, operated from 2003 to 2010, but after its collapse, new VCMs emerged in the following decade (Mendelsohn, Litan, & Fleming, 2022). VCMs were seen to bridge the gap between current climate actions and the climate ambitions set (Miltenberger, Jospe, & Pittman, 2021). They were projected to grow significantly to meet the increased demand for climate solutions in the private sector. These markets provided financial incentives for climate action, developing mitigation strategies, and rewarding GHG offsets.

In recent years, there has been a significant surge in corporate interest in VCMs, nearly tripling in spite of the COVID-19 economic fallout (Streck, 2021). This trend underscores the corporate world's increasing pressure to demonstrate proactive engagement in climate change mitigation. By 2020, companies representing over $12.5 trillion in revenue and 3.5 gigatons of annual greenhouse gas emissions set net-zero climate targets. These commitments vary in scope and coverage, but most aim for carbon neutrality by 2050. Such targets necessitate clear pathways towards reducing GHG emissions in line with the Paris Agreement's goal of limiting global warming to 1.5 °C compared to pre-industrial levels. The voluntary carbon market has played an important role in facilitating these ambitions. Figure 2 illustrates the evolution of the market size in the Voluntary Carbon Market from 1996 to 2022, as tracked through issuances and retirements of credits. Initially, the volume of credits (both issuances and retirements) was minimal, showing little activity in the earlier years. However, there is a notable increase starting around 2010, with a significant surge in issuances from 2018 onward, indicating a rapid expansion of the market in recent years. This expansion is attributed to VCMs providing a platform for investments in offsets as a transitional strategy to accelerate progress towards carbon neutrality and, in the long term, to offset residual unavoidable emissions.

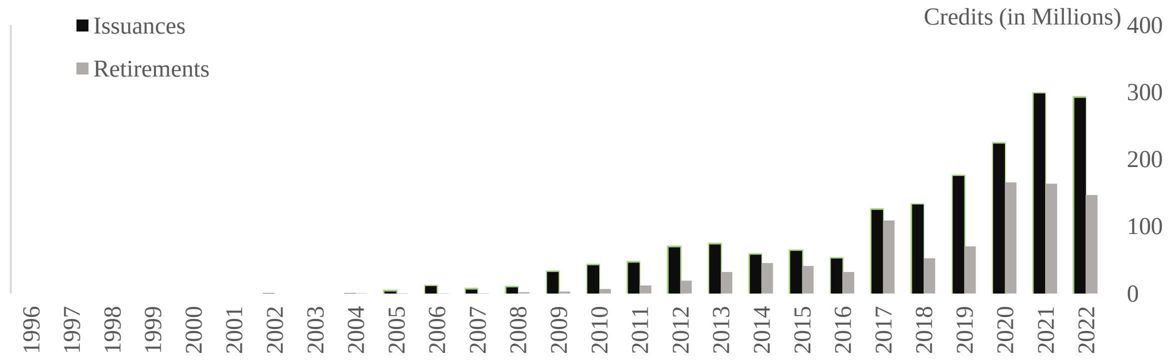


Figure 2 Evolution of the market size in the Voluntary Carbon Market retrieved from the Voluntary Registry Offsets Database version 7 with data from American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard, and Verra (VCS) (Haya, Abayo, So, & Elias, 2022).

2.1.2 The Voluntary Carbon Markets tackling Climate Change

Carbon credits, also known as carbon offsets or Verified Emissions Reductions (VERs), are a measurable reduction or elimination of one metric ton of CO2e (carbon dioxide equivalent) from the atmosphere (Carbon Credits, 2024). The VCM trades billions of dollars in carbon credits annually and in 2022, it directed investments exceeding $1.2 billion, resulting in the reduction of approximately 161 megatons of carbon emissions (World Economic Forum, 2023). This market not only plays a critical role in reducing emissions but also fosters awareness and incentivizes the development of new carbon-reducing technologies. It’s a vital mechanism in financing the global transition to a 1.5-degree scenario, emphasizing the urgent need to cut emissions.

The concept of carbon offsetting involves the act of compensating for emissions generated in a particular region by preventing or eliminating an equivalent quantity of emissions in another location (Macquire, 2022). The mechanism plays an important role in VCMs, as it offers an array of options for organizations to achieve their objectives of carbon neutrality. Nevertheless, the environmental consequences of carbon offsetting initiatives exhibit significant variation and are subject to the influence of numerous factors. An essential factor to consider pertains to the nature of projects that yield carbon credits. As exemplified by the research conducted by Bomfim et al. (2022), initiatives centred on reforestation or forest conservation not only facilitate carbon sequestration but also yield biodiversity advantages and contribute to the safeguarding of ecological systems. Conversely, initiatives within the renewable energy industry play a significant role in mitigating forthcoming emissions and facilitating the shift towards a low-carbon economic model.

A study by Lou, Hultman, Patwardhan, & Irving (2023) investigates corporate motivations and co-benefit valuation in private climate finance investments through voluntary carbon markets. The study identifies three primary corporate motivations for investing in carbon offset projects: achieving carbon neutrality, contributing to company values, and enhancing market competitiveness. The study reveals that companies driven by values and market competitiveness are more inclined to invest in high-cost projects that offer significant local co-benefits. In contrast, companies focused on carbon management and efficiency show a preference for lower-cost projects, especially those related to renewable energy. This distinction indicates a complex dynamic where different corporate motivations lead to varied investment behaviours in the voluntary carbon market. They highlight the importance of understanding these corporate motivations to better comprehend how financial flows in voluntary carbon markets are directed and how they can effectively contribute to climate action. The research suggests that while achieving carbon neutrality remains a primary driver, the pursuit of co-benefits and market advantages also plays a role in shaping corporate strategies in climate finance investments.

A study by Olsen (2007) provides an examination of the Clean Development Mechanism under the Kyoto Protocol, particularly focusing on its contribution to sustainable development. This study illustrates the ideas of the Clean Development Mechanism, which are important to understand because the Voluntary Carbon Market projects are structured similarly. The CDM helps developing nations achieve sustainable development by facilitating investments in clean technologies and practices, and it permits developed nations to partially meet their Kyoto Protocol emission reduction obligations by purchasing credits from CDM projects in developing nations, where emission reduction is typically less expensive (UNDP, 2003). The study by Olsen (2007) systematically reviews the literature to assess how CDM projects have addressed sustainable development goals in host countries. Olsen's analysis identifies several critical aspects related to the performance and impact of CDM projects. One of the key findings is the variability in how different host countries prioritize and integrate sustainable development objectives within their CDM frameworks. The study highlights that while some countries have made considerable efforts to align CDM projects with broader sustainable development goals, others have not, leading to a diverse range of outcomes in terms of sustainability impact. The study also sheds light on methodological challenges and differences in defining and measuring sustainable development outcomes. This includes the debate over whether CDM projects should primarily focus on reducing greenhouse gas emissions or if they should also prioritize local development benefits. Olsen concludes that, while the CDM has the potential to contribute significantly to sustainable development in host countries, its effectiveness largely depends on how individual projects are designed and implemented. The study suggests that for CDM to fully realize its potential, greater emphasis should be placed on developing and applying sustainability criteria and ensuring that projects deliver tangible benefits to local communities.

Considering the project's outcomes' dependability, it is important to note that carbon credits are issued by reliable certification registries that apply strict scientific procedures to ensure accuracy and reliability (Spilker & Nugent, 2022). The issuance of these certificates is a vital component of the VCM, where they are traded to support efforts to decrease and eliminate emissions. Carbon registries improve transparency, accountability, and credibility in the VCM by storing important documents, project histories, and audit data. They act as intermediaries between project developers and buyers as shown in Figure 1, ensuring that the offsets being sold deliver the promised environmental benefits. The effective administration of carbon credits within these registries requires the establishment of operational protocols and a robust technical framework.

2.1.3 Efficiency of carbon projects

The VCM's influence goes beyond simple carbon calculation. It represents the interaction between corporate strategies for achieving sustainability objectives and the concrete results of carbon offset projects in various geographic and socio-economic settings (Gold Standard, 2024). Comprehending these dynamics is essential for individuals and corporations involved in the VCM to maximize their contributions to global climate mitigation endeavours, while also acknowledging the wider consequences of their actions in terms of local development and environmental stewardship.

The efficacy and real environmental impact of carbon projects depend on various factors, and the range of project performance within the CDM framework provides a useful benchmark for comprehending the diverse characteristics of projects within the wider VCM. Prominent among these concepts are additionality and permanence, which have been examined in academic studies such as the study conducted by Castro and Michaelowa (2008), with a specific emphasis on the Clean Development Mechanism. They highlight that the success of carbon offset projects is influenced by various factors, including host country dynamics, project type, and the strength of the argument for additionality. These factors indicate that the outcome of such projects depends on a combination of elements, ranging from local political and economic contexts to technical project specifications. The study of CDM projects' performance indicates a notable lack of success in numerous projects, as consultants frequently overestimate the potential for reducing emissions, resulting in a lower number of CERs being issued than anticipated. The timing of CER generation is often affected by delays in project initiation, which are influenced by host country-specific factors such as regulatory approvals. Bilateral projects typically exhibit superior performance compared to unilateral ones, owing to their access to superior resources and support. Exhibiting additionality and guaranteeing sustainability pose significant obstacles, although they do not have a direct influence on the issuance of CER or the success of projects in validation or registration.

A recent study by Fujii et al. (2024) analyses the evolution of the voluntary carbon offset market from 2006 to 2020, focusing on the key drivers of changes in the volume of carbon credits issued. The study employs a decomposition analysis framework to understand these changes. The study found that for variation in priority changes, the reasons for changes in the priorities of carbon credits issued varied according to the scale of carbon offset programs in different regions. A usefulness of scale effect analysis showed that the comparison between the scale effect and the priority of carbon offset programs was found to be a valuable tool in understanding the changes in carbon credits issued across different technologies and regions. The study underlines the necessity for policy reform, considering the reliance on carbon credits and the challenges posed by their rapid increase. The research contributes to understanding the dynamics of the voluntary carbon offset market, highlighting the importance of examining the driving factors behind the issuance of carbon credits.

Another study of the VCM sheds light on its role in addressing global warming and its potential to support the development of less carbon-intensive economies (Battocletti, Enriques, & Romano, 2023). It acknowledges the significant market capitalization of companies with climate targets, highlighting their reliance on carbon offsets to achieve these goals. The study identifies key issues in the VCM, such as conflicts of interest and imperfect information, which hinder its effectiveness. They critique current regulatory proposals in Congress as misguided and offer an alternative proposal aimed at improving the VCM’s functionality which includes increasing the likelihood of firms relying on high-quality offsets to fulfil their climate commitments.

2.1.4 Critiques and Challenges

The preservation of the environmental integrity of carbon credits has been a prominent issue in the VCM. A study conducted by West et al. (2020) uncovered potential misrepresentation of emission reductions reported by voluntary REDD+ projects in the Brazilian Amazon. This finding raises concerns regarding the credibility and legitimacy of the credits associated with these projects. This raises the concern for its efficacy in effectively mitigating real climate change. Also, according to studies by Kreibich & Hermwille (2020) and Valiergue & Ehrenstein (2022), the VCM is criticized for enabling companies to avoid making real reductions in emissions by purchasing offset credits. They highlight a possible imbalance between the supply of offset credits and the increasing demands of the private sector. They emphasize that offsetting should not be seen as a convenient solution, but rather as a complement to genuine efforts to achieve net-zero emissions.

In addition, the management of the VCM is decentralized and shows substantial variation among different standards and certification systems. Ahonen et al. (2022) observe that the shift from centralized governance in the Kyoto Protocol to decentralized approaches adopted by the Paris Agreement has led to fragmentation. This has led to the rise of private institutions that are now playing a more significant role outside of the conventional regulatory frameworks. The presence of fragmentation has the potential to cause inconsistencies in the validation and verification procedures of carbon credits. The study is also looking at the issue of double counting, which occurs when multiple parties claim credit for the same emission reduction. The intricacies of making necessary changes, specifically in relation to Article 6 of the Paris Agreement, are a topic of ongoing discussion to ensure that the same carbon credit is not double-counted in the national accounting of different countries. In addition to the issue of differing standards, there are concerns such as the absence of a uniform quality or certification standard for offset providers, and the risks of misleading claims and market inefficiencies (Dhanda & Hartman, 2011). There is a need of the establishment of a clear, universally understandable set of criteria for offset providers to rectify the current “cowboy atmosphere” marked by dubious practices.

Voluntary carbon markets are increasingly recognized as an important component of future climate action strategies, despite current critiques regarding their transparency and efficiency (Miltenberger, Jospe, & Pittman, 2021). These markets are not only poised for significant impact but are also capable of attracting substantial financial investments. There are also several opportunities for innovation, emphasizing the need for improved governance, technological advancements, and greater stakeholder inclusion to address inequities and optimize VCMs’ effectiveness in climate action. The existing challenges within VCMs are seen as opportunities for essential improvements that will drive broader climate ambitions and help meet global targets. By 2050, VCMs are expected to become integral to global economies, facilitating extensive decarbonization and economic restructuring (DNV, 2023). This vision emphasizes the need for VCMs to evolve, incorporating high standards, adaptability, and wide stakeholder participation to effectively catalyse climate action.

2.2 Hypothesis setup

In this thesis, I aim to explore the dynamics and underlying factors influencing projects in the VCM. Specifically, I am interested in understanding whether factors such as geographical and technological (sectoral) aspects have a distinct impact on the trends and effectiveness of carbon offsetting projects such as the same done in the study by Castro & Michaelowa (2008). The previous chapter laid out a theoretical foundation, drawing from environmental economics and carbon market dynamics. However, the practicalities of VCM participation and the efficiency of projects are not as straightforward as theory might suggest. In many instances, the performance and engagement in the VCM are driven by a mix of environmental, economic, and technological factors. This mix can manifest in various ways, such as regional environmental policies influencing technology adoption in carbon offset projects, or technological advancements shaping regional participation in the VCM. Acknowledging the complexity of these interactions, my focus will be on examining the trends in VCM participation and performance across different regions and technologies, while remaining open to uncovering other influential factors. It is important to note that even if the hypotheses I develop are supported, they may not represent the sole factors influencing VCM dynamics. All hypotheses should be viewed as “alternative hypotheses”, with the corresponding null hypothesis being that “there are no significant differences in VCM participation and performance across different regions and technologies”.

One key challenge in this research is quantifying and comparing the impact of geographical and technological factors on VCM performance. Since there is typically no direct data available on why certain regions or technologies are more engaged or successful in the VCM, I must rely on indirect measures and statistical methods. My approach mirrors that of landmark studies in this field, like the work of Fujii et al. (2024). The study conducted by Fujii emphasizes the absence of an analysis of the voluntary carbon market from a macro perspective, as well as the analysis of trend changes across different regions and technologies. My contribution lies in applying these hypotheses to a more comprehensive dataset, scrutinizing them through the lens of regional and technological variances.

Additionally, caution must be exercised in interpreting correlations as causations. For example, a strong presence of a particular technology in the VCM from a specific region does not necessarily imply that the region’s environmental policies directly caused this. However, patterns and trends can offer insights into possible motivations and outcomes. Following this, I will refine the research question into precise, empirically testable hypotheses.

2.2.1 Regional and Sectoral Effectiveness of Carbon Offset Projects

The first aspect I will examine in this thesis is the variation in the effectiveness of carbon offset projects in reducing CO2 emissions across different geographical regions and sectors. This hypothesis stems from the understanding that regional environmental conditions, technological advancements, and sector-specific dynamics play an important role in the success of these projects.

The effectiveness of carbon offset projects, such as those involving reforestation or renewable energy, is not uniform across different regions. This discrepancy can be attributed to various factors, including geographical climate conditions, available technologies, and regional policies. For instance, reforestation projects might be more successful in tropical regions compared to arid areas due to differences in climate and biodiversity. Similarly, the effectiveness of renewable energy projects can vary depending on regional technological capabilities and resource availability. This hypothesis aligns with the findings of studies like those by Bomfim et al. (2022), highlighting the diverse environmental impacts of different project types.

Moreover, sectoral differences play a significant role in the carbon offset market. For example, the energy sector may have different potentials and challenges in carbon offsetting compared to the agricultural sector. These differences can influence the overall effectiveness of carbon offset projects in reducing CO2 emissions. The study by Fujii et al. (2024) provides valuable insights into the evolution of the voluntary carbon offset market, emphasizing the importance of examining the driving factors behind the issuance of carbon credits across different technologies and regions.

This hypothesis aims to shed light on the nuanced ways in which geographical and sectoral factors influence the success of carbon offset projects. By analysing data across various regions and sectors, this research seeks to understand better and quantify the effectiveness of carbon offset projects in mitigating CO2 emissions.

Hypothesis 1: "The effectiveness of carbon offset projects in reducing CO2 emissions varies significantly across different geographical regions and sectors".

2.2.2 Project Scale, Success, and Classification in the VCM

As we delve deeper into the complexities of the VCM, it becomes evident that a multifaceted approach is needed to understand the intricacies of project success. This section aims to dissect the VCM further, focusing on the scale of projects, the classification of their success, and the regional differences in project outcomes. These aspects are essential in shaping the trajectory and impact of carbon offset initiatives. Building on the initial exploration of the complexities within the VCM, it is imperative to integrate findings from pivotal studies that provide a deeper context and understanding. The studies by Castro & Michaelowa (2008) and Fujii et al. (2024) offer critical insights that bolster the framework of hypotheses.

Castro & Michaelowa (2008) emphasize the importance of contextual factors in the success of carbon offset projects. Their analysis suggests that factors such as regional policies, local economic conditions, and technological capabilities significantly influence project outcomes. This perspective aligns closely with Hypothesis 3, which posits that projects in developed regions, typically equipped with better infrastructure and more robust regulatory frameworks, are likely to issue more credits than those in developing regions. Also, a study by Mathur et al. (2014) shows that carbon market projects in developing countries often fail to deliver significant benefits to host communities, primarily focusing on global carbon emission reductions. Furthermore, the study reveals that these projects frequently marginalize local communities in decision-making processes, exacerbating existing inequalities and limiting their ability to protect their interests and advance their claims within the multi-level governance structures.

Meanwhile, Fujii et al. (2024) provide an overview of the voluntary carbon offset market, highlighting the variability in trends of carbon credit issuance across different technologies and regions. Their study underscores the diverse nature of project success in the VCM, influenced by a myriad of factors including project scale, type, and regional characteristics. This aligns with Hypothesis 2, suggesting that larger-scale projects are more likely to achieve successful credit retirements.

These studies collectively reinforce the need for a nuanced approach to analysing the VCM. They illustrate that understanding the success of carbon offset projects requires examining a broad spectrum of factors, from project scale and specific characteristics to regional disparities. This analysis is important for deriving actionable insights and formulating strategies that can enhance the effectiveness of carbon offset initiatives in the global fight against climate change. In light of these considerations, the following hypotheses are proposed for exploration.

Hypothesis 2: "Larger-scale projects in the VCM are more likely to have more effective projects compared to smaller-scale projects".

Hypothesis 3: "Projects in developed regions are more effective than those in developing regions, influenced by factors like infrastructure and regulatory frameworks".

2.2.3 Impact of Regional Carbon Pricing Mechanisms on Credit Issuance

Another aspect is the potential influence of regional carbon pricing mechanisms, like carbon taxes or emissions trading systems, on the rate of credit issuance in the VCM. The hypothesis is formulated on the premise that regions with established carbon pricing strategies might exhibit different patterns in carbon credit issuance compared to regions without such frameworks.

This hypothesis builds upon the insights provided by Fujii et al. (2024), who conducted an in-depth analysis of the VCM, focusing on the changes in priority and scale of carbon credits issued. Their study emphasizes the variation in trends of carbon credit issuance across regions and technologies, yet it stops short of specifically exploring the impact of regional carbon pricing mechanisms on these trends. This gap signals a need for additional research to delve into how regulatory and economic environments shaped by carbon pricing strategies could influence the VCM. For instance, it is plausible to hypothesize that regions with carbon taxes or cap-and-trade systems may create more incentives for carbon offset projects, potentially leading to a higher rate of credit issuance.

However, the relationship between regional carbon pricing mechanisms and the rate of carbon credit issuance in the VCM is not yet clearly understood and warrants further empirical investigation. Given the complexity of factors influencing the VCM, such as policy environments, market dynamics, and project-specific attributes, this hypothesis aims to untangle these influences and provide a clearer understanding of how policy frameworks impact the market's functioning.

Hypothesis 4: "Projects in regions with established carbon pricing mechanisms (like carbon taxes or emissions trading systems) are more effective than those in regions without such mechanisms".

3. Experimental Setup

The study seeks to clarify the complexities governing the effectiveness of carbon offset projects through a primarily explanatory approach. This investigation is not limited to correlations; rather, it delves into causality, attempting to understand how various project characteristics from a large database contribute to their overall effectiveness in carbon mitigation. This research is based on quantitative analysis and makes extensive use of data from the Berkeley Voluntary Registry Offset Database (Haya, Abayo, So, & Elias, 2022). As noted by Mendelsohn, Litan, & Fleming (2022), establishing standards for project verification is essential for ensuring the genuine effectiveness of carbon markets. This study brings together projects from four leading registries, providing a broad view of the VCM landscape. The breadth of historical data supports the exploratory nature of this study, positioning it as a longitudinal analysis in which temporal dimensions of projects are acknowledged, but are not the primary focus.

Using a comparative lens, the study compares projects from various regions and scopes, looking for patterns and deviations that can inform the VCM's effectiveness. Streck (2021) emphasizes the importance of an analytical framework to capture the diverse impacts of voluntary carbon markets, particularly in developing countries, which aligns with this study's methodological approach. Inspired by the approach in Lee, Kim, & Kim (2018), this research adopts a statistical technique to analyse the effectiveness of carbon offset projects (Lee, Kim, & Kim, 2018). Their study successfully utilized regression analysis to discern the impact of co-benefits on the pricing of carbon credits in the voluntary carbon market, demonstrating the value of integrating such variables into regression models to enhance the comprehensiveness of the analysis. This insight builds up on the analytical tools used such as comparative analysis and regression in this thesis. These techniques will act as an analytical compass, guiding the investigation toward a thorough understanding of the dataset, and ensuring that the different characteristics are analysed to uncover underlying patterns that might influence the effectiveness of carbon offset projects.

Data handling is an important step when handling the scope of the VCM. The inclusion of the four largest registries, which are intended to capture the majority of the market's breadth, enhances the sample's representativeness. The operationalization of variables has been based on the current VCM literature. Effectiveness, the dependent variable, is calculated using a lens that examines the percentage of retired credits based on the issued credits, providing a tangible measure of project success. Independent variables include scale, region, scope, developing status, and carbon mechanisms, and each is precisely defined to ensure clarity in analysis. Methodologically, this study employs a variety of statistical techniques, recognizing the difficulties of capturing the VCM's complexity in a single model. I am using analytical tools such as benchmarking and different regression models such as beta, OLS, and Tobit to capture a wide range of models to test the data.

Anticipated challenges, particularly the difficult fit of data to one regression model, are addressed through the strategic deployment of multiple tests to improve understanding. This approach also addresses potential limitations, such as the questionable validity of statistical findings due to model fit, by offering a variety of analytical perspectives. Ethical considerations, while not a difficult path in this research journey, are navigated to ensure the study contributes insightfully to a market that is frequently clouded by scepticism. Drawing from Dhanda & Hartman (2011), this study is mindful of the ethical complexities in carbon markets, ensuring that the findings not only advance academic knowledge but also adhere to ethical standards.

The findings are expected to shed light on some of the most enigmatic influences on project effectiveness within the VCM. These findings will be communicated through regression tables, graphical representations, and a narrative intended to clarify the often-turbulent waters of carbon offsetting effectiveness.

3.1 Data Collection and Preparation

The basis of this preliminary investigation is the Berkeley Voluntary Registry Offset Database Version 7 *(Haya, Abayo, So, & Elias, 2022)*, which is a collection of data in the VCM. This essential compilation gathers data from four prominent registries: the American Carbon Registry (ACR), the Climate Action Reserve (CAR), the Gold Standard (GOLD), and the Verra Registry (VCS). The dataset comprises a total of 7,466 distinct projects, which includes different information about the projects. The data included in the database used for this thesis is presented in Appendix Tables A.1 and A.2. The provided information presents a breakdown of the content covered by various scopes and the specific countries encompassed within each region.

Categorization is essential for determining a project's impact on the VCM using the important measures of Credits Issued and Credits Retired. These metrics act as indicators for the feasibility of a project and its compliance with established carbon reduction standards. To ensure analytical rigor, projects that did not issue any credits were deliberately excluded from the dataset, resulting in a refined focus on 4,001 projects that were active in issuing credits. The separation the dataset makes it easier to create a clear representation of the effectiveness of VCM. To improve the relevance of the dataset I added two more data columns regarding the host country of projects. The first column marked as either “developing” or “developed” shows the classification from the UNDP about its status (UNDP, 2024). I had to classify Kosovo manually as “developing” after being excluded from the UNDP database. This ensures global representation and avoids unintentional omissions. The second column added “Carbon mechanism” shows either “Yes” or “No” for a country describing if it has implemented a Carbon mechanism in the country. This data is gathered from the World Bank dashboard about carbon mechanisms (World Bank, 2024).

In the dataset, there are some outliers in the effectiveness data where projects exhibit effectiveness values greater than one, which is theoretically impossible. For the purposes of the analysis, these outliers have been adjusted to a maximum value of 1 in the regression models.

3.2 Variables

The variables considered to understand the factors influencing effectiveness of carbon offset projects is described in this section. Each variable considered for this study is detailed in Table A.3 in the Appendix, which provides an overview of the variables’ descriptions, their relevance and irrelevance to the research questions, and references to previous research that supports their inclusion. The variables Scope, Region, Total Credits Issued, Total Credits Retired, Developing Status, Carbon Mechanism, Scale, and Project ID were selected due to their relationship with the project effectiveness within the VCM. For example, the variable “Scope” is used to understand the impact of the technologies such as the methodology in the study by Fujii et al. (2024). On the other hand, some variables like “Country” were excluded due to practical constraints such as small sample size, which could potentially skew the research findings. This selection and exclusion of variables were necessary to maintain the analytical clarity of the thesis.

3.2.1 Dependent variable

This paper focuses on the idea of “Effectiveness”, a difficult and evidence-based metric essential for evaluating VCM carbon offset projects. Expressed as the ratio of retired credits to total issued credits, this statistic accurately reflects the main objective of carbon offset programs, the real reduction of carbon emissions. Castro & Michaelowa (2008) provide an examination of how project scale and regional factors significantly impact the issuance of CERs. Their work provides a valuable framework for understanding how localized socio-economic and environmental conditions can affect the overall impact of carbon offset initiatives. By integrating insights from that study, this research aims to build on their foundational findings, beyond just scale and region, to offer an analysis of “Effectiveness” within the VCM. Operational-wise, “Effectiveness” is quantified by calculating the proportion of retired credits to the overall number of issued credits for each project. This ratio, presented as a percentage, offers a precise and standardized metric for evaluating the performance of various projects within the VCM.

$$\frac{Total\ Credits\ Retired}{Total\ Credits\ Issued} = Effectiveness$$

The study seeks not only to show patterns in the effectiveness of carbon offset projects but also to provide actionable insights for improving practices and decision-making in the VCM. By operationalizing the concept of “Effectiveness” through a broad strategy, the thesis is anticipated to yield reflective insights into the factors contributing to the success of carbon offsetting. This analysis aims to offer a more complete and evidence-based understanding of the variables influencing the VCM, thereby enabling informed policy-making and effective climate action.

3.2.2 Independent variables

The exploration of “Effectiveness” as a dependent variable in this thesis involves an examination of several independent variables that potentially influence project performance. The chosen independent variables included, as described in Table A.3 in the Appendix, are the variables Scale, Scope, Region, Developing Status, and Carbon Mechanism. Table A.1 and A.2 in the Appendix shows a breakdown for the independent variables. This section describes a detailed description of the independent variables.

Scale

Building on the foundational insights from Castro & Michaelowa (2008), this study acknowledges the differential impact of project scale on the effectiveness of carbon offset projects within the VCM. Castro & Michaelowa’s study underlines that smaller projects often yield better outcomes in terms of CERs issuance, compared to their larger counterparts. In alignment with this, the current study employs a binary classification of project scale based on the median value of issued credits. Specifically, projects are categorized into two groups: “Small” for those below the median and “Large” for those above the median. This segmentation facilitates a detailed examination of how project size influences the effectiveness of carbon offset initiatives. There are 2,001 small and 2,000 large project scales in the distribution.

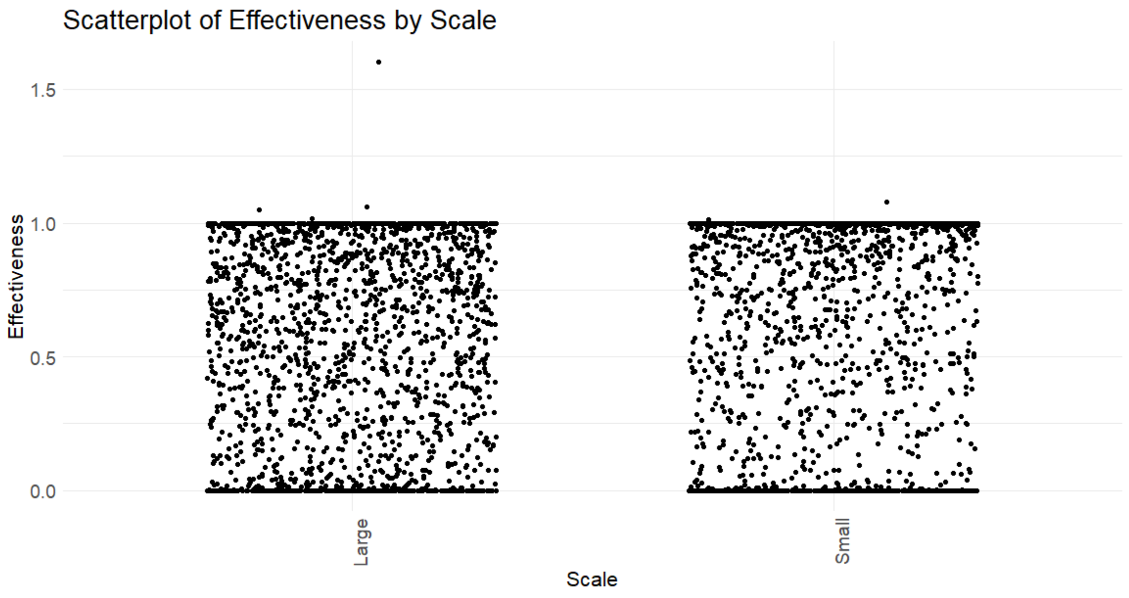


Figure 3 Scatterplot of effectiveness on project size split into large and small Scale.

The scatterplot of "Effectiveness by Scale" visually distinguishes the effectiveness of carbon offset projects categorized as "Large" and "Small". The plot shows a significant number of data points clustered around the lower effectiveness range for both categories. Looking at the plot, one can see that compared to small-scale projects, more projects are situated in the middle for the large scale. However, there are a few outliers, particularly in the "Large" category, which reach higher effectiveness levels something that does not make sense. Notably, both categories demonstrate a dense clustering of data points at lower effectiveness levels.

Region

Geographic location also plays a critical role in shaping the outcomes of carbon offset projects, as demonstrated in Castro & Michaelowa's (2008) study, which showed varying levels of success across different regions. This study adopts a similar approach by defining specific geographic boundaries that help categorize projects based on their environmental and socio-economic contexts. This differentiation enables a nuanced comparative analysis of how location influences project effectiveness. For instance, projects in industrialized regions might show different effectiveness dynamics compared to those in developing regions, where technological and financial constraints play a significant role. This understanding is important for stakeholders involved in the design and scaling of carbon offset projects. It provides valuable insights into which strategies are more likely to succeed in certain regions, thus allowing for better planning and implementation of carbon offset initiatives. This approach facilitates a layered comparative analysis, enabling an examination of effectiveness across different factors.

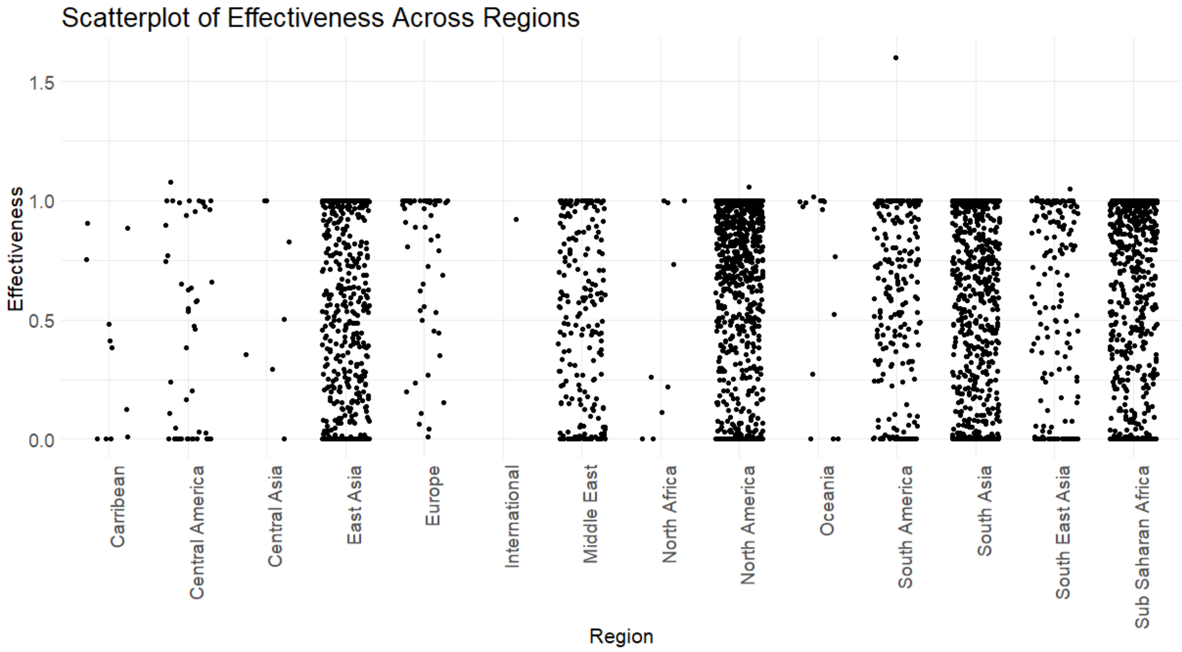


Figure 4 Scatterplot of effectiveness across Region.

The scatterplot provides a view of how geographic location impacts the effectiveness of carbon offset projects across different regions. The distribution of effectiveness across regions like East Asia, North America, and South Asia shows a broad spread of data points as shown in the Table 1 below. This variability may reflect diverse environmental policies, project management efficiencies, and local socio-economic conditions. Most of the projects in North America are in the US and for East Asia they are located in China. Projects that involve shipping and are not officially registered in any specific country are classified as “International”. This classification also applies to projects that involve multiple countries.

Table 1 Distribution of number of projects across regions.

Region	#	**Region**	#	**Region**	#
Caribbean	11	International	1	South America	237
Central America	53	Middle East	216	South Asia	794
Central Asia	7	North Africa	9	South East Asia	173
East Asia	616	North America	1157	Sub Saharan Africa	658
Europe	55	Oceania	14		

As shown in Table 1, regions like the Caribbean and Central America show a lower density of data points, which indicates fewer projects. It is important to consider the implications of using a small number of projects in the analysis, as this can potentially result in misleading findings. This variable highlights the importance of considering geographic factors when assessing the performance of carbon offset projects. The regional differences observed here can be instrumental for policymakers and project managers in understanding and improving carbon offset strategies tailored to specific regional conditions.

Scope

The scope of carbon offset projects encompasses a wide array of fields, each characterized by distinct environmental implications and operational challenges that significantly influence their effectiveness in achieving carbon mitigation goals. The studies by Bomfim et al. (2022) and Fujii et al. (2024) highlight the importance of examining the variation in the effectiveness of carbon offset projects in reducing CO2 emissions across sectors, emphasizing the role of regional environmental conditions, technological advancements, and sector-specific dynamics. The scopes in the database range from agriculture, forestry, and land use to more technologically intensive industries like renewable energy and carbon capture & storage. This diverse categorization allows for a nuanced analysis of project effectiveness, assessing how specific characteristics inherent to each scope affect outcomes. A detailed overview of the different scopes with included technologies can be found in Table A.2 in the Appendix.

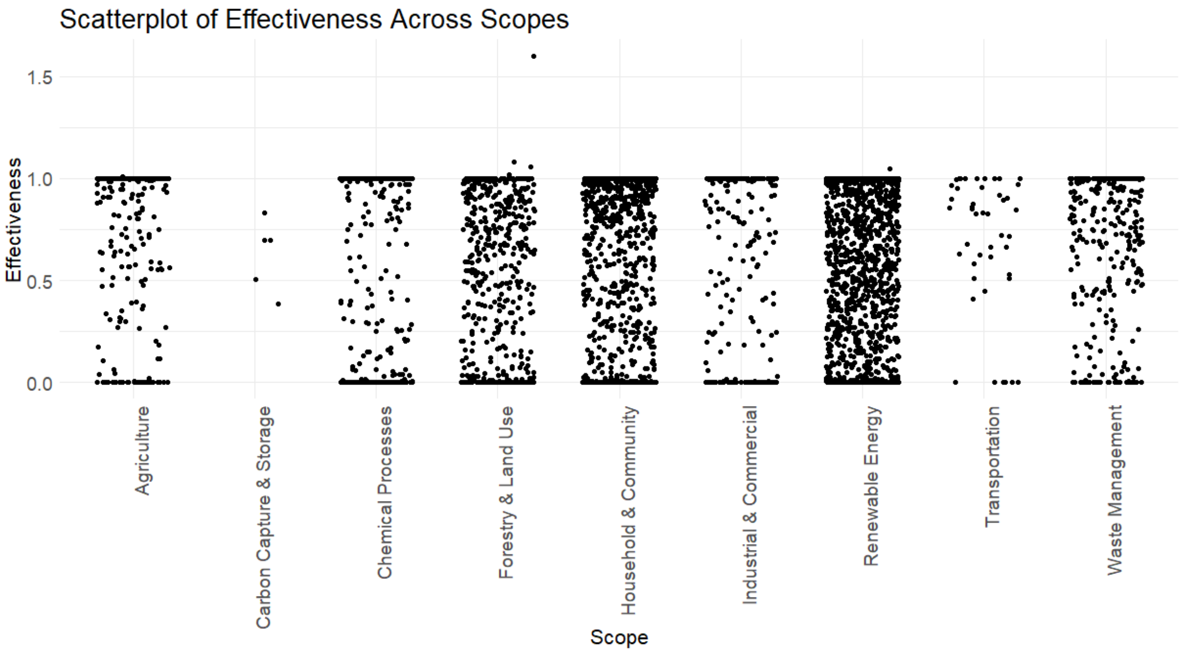


Figure 5 Scatterplot of effectiveness across technology Scope.

The scatterplot above shows the distribution of effectiveness on the y-axis and scopes of different technologies on the x-axis. The density of projects related to Renewable Energy is noticeable. Renewable energy sources play a role in decreasing dependence on fossil fuels. The extent to which they are successful can be affected by advancements in technology and support from policies. On the other hand, Carbon Capture & Storage shows a minimal existence in this dataset with only 5 projects. This technology represents a scientific method for decreasing atmospheric CO_2 levels. However, the technology is not yet available for commercial use. Projects in the Household & Community sphere frequently focus on small-scale initiatives and are typically situated in developing countries. These projects can have substantial social impacts. From the Table 2 one can observe that Renewable Energy has 1391 projects, highlighting a strong focus in this area, due to global pushes for renewable initiatives. Forestry & Land Use and Household & Community also shows a strong track record of projects. This detailed breakdown aids in understanding not just the number of projects per scope but their potential impact on overall effectiveness. Each scope's unique challenges and opportunities for carbon reduction are critical for developing targeted strategies that enhance their performance and, by extension, the efficacy of the carbon offset projects overall.

Table 2 Distribution of number of projects across technology Scope.

Scope	#	Scope	#	Scope	#
Agriculture	258	Forestry & Land Use	536	Renewable Energy	1391
Carbon Capture & Storage	5	Household & Community	899	Transportation	46
Chemical Processes	346	Industrial & Commercial	210	Waste Management	310

Developing status

In the analysis of carbon offset projects, the classification of countries into "Developed" and "Developing" categories plays a essential role, reflecting differing economic capabilities, technological access, and policy environments. This distinction, based on classifications from the United Nations Development Programme provides a framework for understanding how socio-economic and developmental statuses impact the effectiveness of carbon mitigation efforts. The projects are distributed with 2879 projects located in developing countries compared to 1122 projects in developed countries.

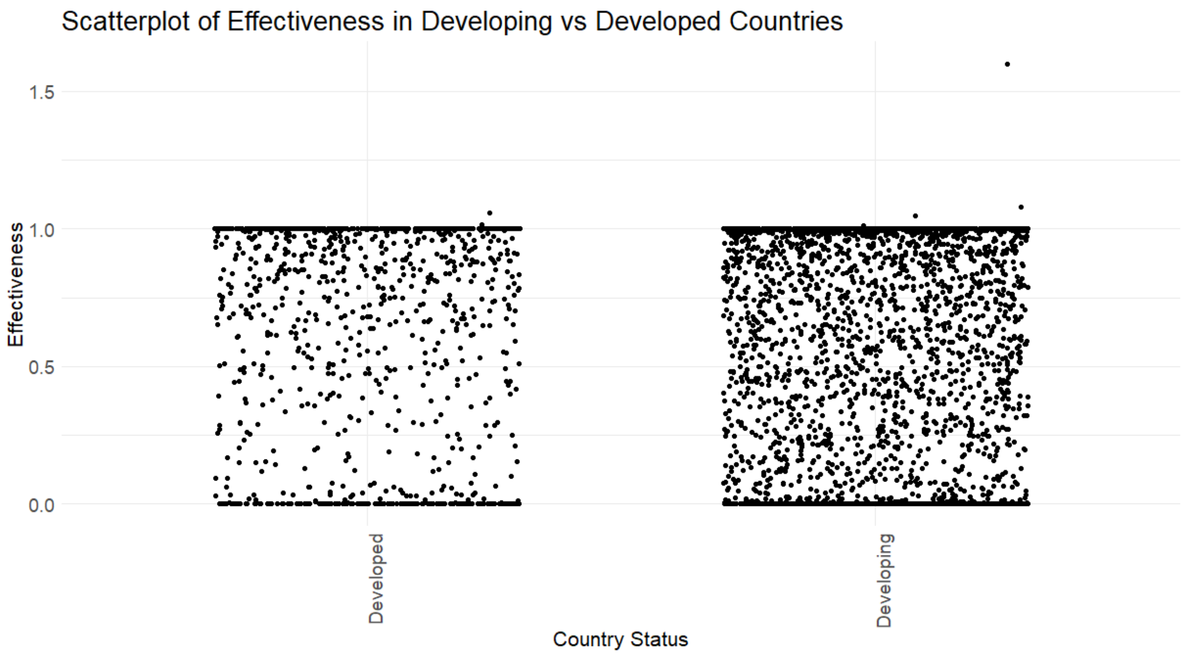


Figure 6 Scatterplot of effectiveness for developing status for project location.

The scatterplot of effectiveness in Developing vs. Developed countries visually underscores the variability and range of project outcomes within each category. Notably, both developed and developing countries exhibit a broad and similar spread of effectiveness scores, ranging from low to high, but with a dense concentration of data points clustered near the mid to high effectiveness range. This visual analysis suggests that the effectiveness of carbon offset projects does not necessarily correlate directly with a country's development status. Instead, other factors such as project management, technology implementation, and local environmental policies might play more critical roles as Fujii et al. (2024) show in their study. The data prompts further investigation into the specific attributes of projects in developing countries that lead to high effectiveness, potentially offering insights into how similar strategies can be replicated or adapted in other regions. By examining these differences, stakeholders can better understand the challenges and opportunities in both developing and developed contexts, tailoring approaches that maximize the impact of carbon offset projects.

Carbon Mechanism

The introduction of the "Carbon Mechanism Implementation" variable provides a lens through which the effectiveness of carbon offset projects can be analysed, specifically examining whether the presence of carbon pricing mechanisms, such as carbon taxes or emissions trading systems, impacts project outcomes. By distinguishing projects based on whether the host country has implemented such mechanisms (noted as "Yes" or "No"), this study assesses their influence on project effectiveness. According to the World Bank's dashboard on carbon mechanisms, the dataset includes 2038 projects from countries without a carbon mechanism and 1963 projects from countries with such policies in place (World Bank, 2024).

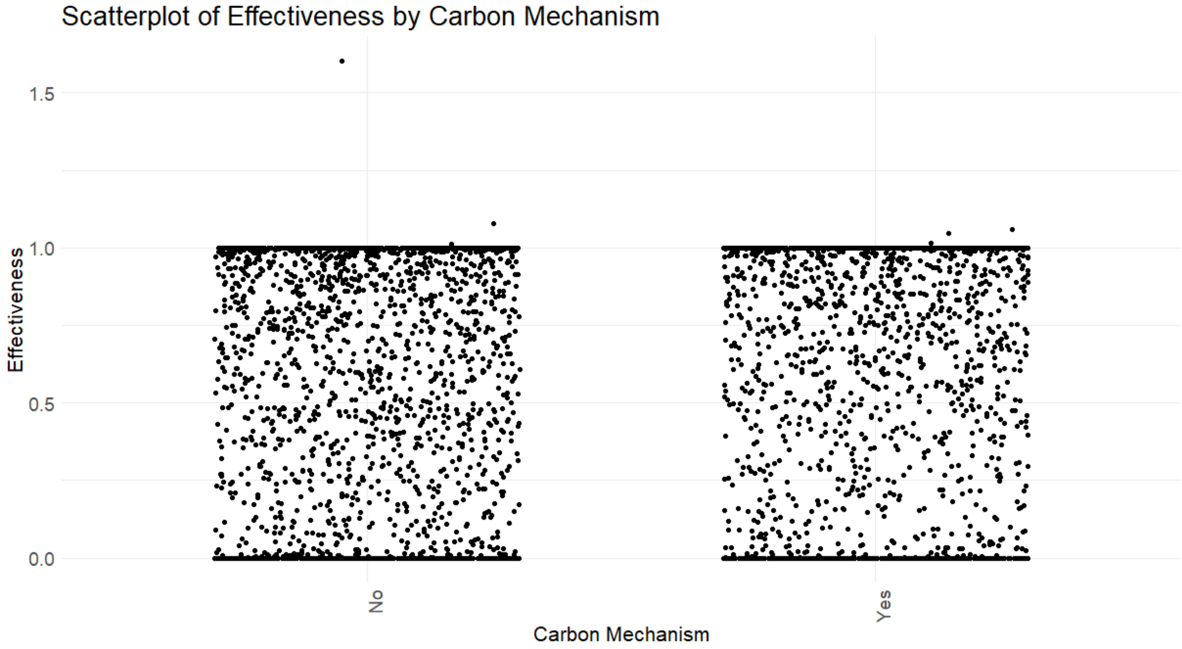


Figure 7 Scatterplot of effectiveness for carbon mechanism implemented for project location.

The scatterplot of effectiveness by carbon mechanism visually presents the distribution of effectiveness across these two groups. Both categories display a dense concentration of effectiveness scores at lower levels and the top. Moreover, there is a nuanced correlation to consider between carbon mechanisms and development status; often, countries with such mechanisms are developed, which could influence project outcomes due to better resources and governance. While this is true for most of the countries, there are developing countries that have implemented a carbon mechanism. The analysis must therefore be cautious about attributing differences in effectiveness solely to the presence of carbon mechanisms. This variable, while valuable, intersects with other socio-economic and policy factors that collectively influence project performance.

3.3 Model and analytical tools

The analytical framework of this study is designed to optimally address and test the hypotheses. Drawing inspiration from the work mentioned in the literature review, a new research design needs to be addressed in the study of this field. This research adopts benchmarking of effectiveness, Beta, pooled OLS, and Tobit regression for the study design.

To improve the ability of this study to explain, practical analytical methods such as benchmarking is employed. The method enhances the analytical framework and offers a contextual comprehension of the effectiveness of carbon offset projects.

In the regression analysis of carbon offset project effectiveness, the selection of baseline categories for categorical variables like region and scope is used for meaningful comparisons. Baselines provide a reference point against which all other categories are measured. For this study, “North America” and “Renewable Energy” were chosen as baselines due to their substantial representation in the dataset and their relevance in global carbon offset strategies. North America, with a diverse array of projects and developed environmental policies, offers a stable benchmark for comparing regional differences. Similarly, Renewable Energy, being the most common project type and central to contemporary carbon mitigation efforts, serves as an ideal baseline for evaluating the effectiveness across different project scopes. These choices ensure that the analysis is grounded in a context that enhances interpretability and relevance, providing a solid foundation for assessing the impact of various factors on project success.

Through an approach that integrates econometric techniques with thorough validation and robustness checks, this study aims to provide a consistent and more detailed view of the factors that influence the effectiveness of carbon offset projects. By grounding the econometric strategy in theoretical and empirical robustness, the thesis seeks to contribute meaningfully to the discourse on sustainable environmental practices within the VCM. The approach reflects the complexities inherent in the data and provides actionable insights that can inform policy and strategic decisions in the realm of carbon offsetting.

3.3.1 Benchmarking Effectiveness

Benchmarking refers to the process of identifying and studying the most effective methods and practices within an industry, which can result in achieving higher levels of performance. (Camp, 1989). The concept underscores a philosophy of continuous improvement where recognizing shortcomings and learning from those performing better is critical (Bhutta & Huq, 1999). This methodology not only encourages recognizing one’s deficits but also fosters an external focus on competitiveness, which often leads to breakthrough thinking (Landry, 1993). This approach is relevant to this thesis, where benchmarking can be used to measure the effectiveness of carbon offset projects. The effectiveness metric acts as a benchmark to assess and compare the performance of different projects, guiding the implementation of strategies that have demonstrated success in achieving superior environmental outcomes, here more credits retired. This use of benchmarking not only helps in understanding current performance levels but also in adopting measures that can lead to enhanced sustainability and operational efficiency in carbon offset initiatives.

The Integrity Council for the Voluntary Carbon Market (ICVCM) plays a role in standardizing and improving the quality of carbon credits, which directly relates to the effectiveness of benchmarking practices within carbon markets (ICVCM, 2023). The ICVCM is tasked with setting forth clear and robust criteria that define what constitutes a high-quality carbon credit (ICVCM, 2024). By establishing these standards, the ICVCM helps ensure that carbon offset projects not only contribute genuinely to carbon reduction but also adhere to principles of environmental integrity and sustainable development. The guidelines and standards set by the ICVCM are instrumental in creating a benchmark for carbon markets globally. For the benchmarking process within carbon markets ensures that the comparisons made are based on consistent and reliable criteria, which is essential for drawing meaningful conclusions about the relative performance. This approach to defining and enforcing quality standards helps drive innovation in carbon offset projects.

Despite the use of benchmarking across various sectors, a review of the existing literature reveals a noticeable gap in the use of benchmarking specifically for assessing the effectiveness of carbon projects. The effectiveness of carbon offset projects is a measure that covers not only the quantity of carbon reduced or sequestered but also the quality and sustainability of these reductions. As highlighted by Streck (2021), understanding the diverse impacts of these projects, particularly in developing regions, necessitates a robust methodological approach that can compare across different projects and standards effectively.

The setup to measure effectiveness in carbon offset projects through benchmarking in this thesis incorporates comparative analysis, which examines variances across the variables scale, region, scope, development status, and carbon mechanism. The process starts by categorizing projects into the different variables, and each category is analysed statistically to provide a view of effectiveness, employing measures such as mean, median, quartiles, and distribution ranges. This benchmarking process creates the indicator “Effectiveness” and compares it across the different factors. Additionally, the thesis examines the performance of various regions across different scopes. By systematically analysing effectiveness across these variables, this benchmarking approach identifies best performer categories that give insights to drivers of effectiveness.

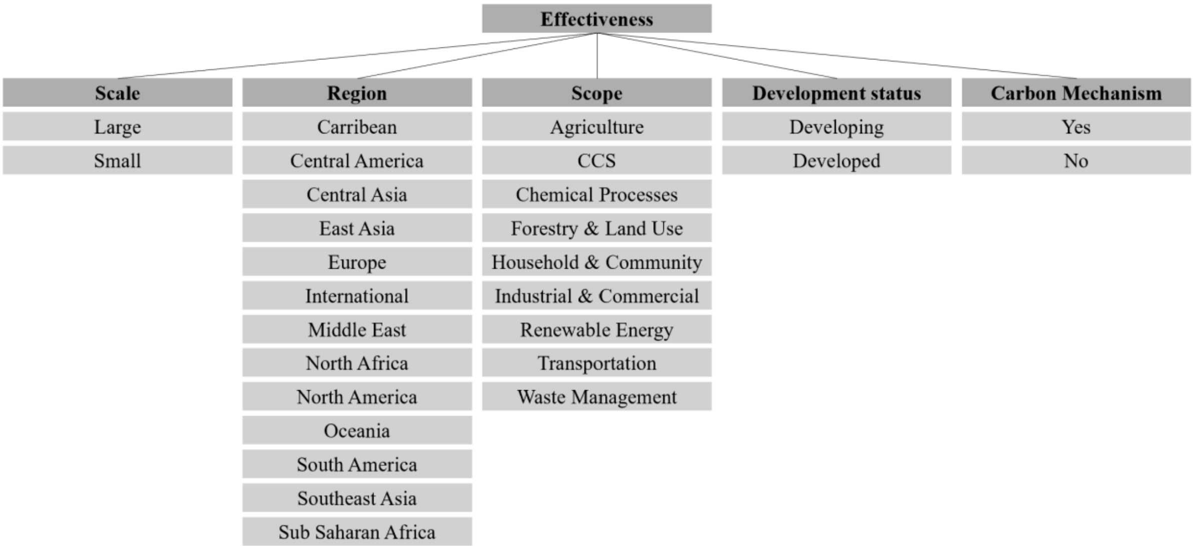


Figure 8 For illustrative purpose. The setup for benchmarking effectiveness across independent variables. The analysis also benchmarks effectiveness the different regions across the scopes.

By aligning the benchmarking process with ICVCM standards, this study can provide more insights by setting an effectiveness benchmark of historical carbon projects, guiding project developers and investors. The need for such an approach is underscored by the absence of studies specifically addressing how different carbon offset projects measure up against each other in terms of their actual environmental impact. Through this benchmarking process, the study aligns with the broader strategic objectives of enhancing transparency, accountability, and effectiveness in the voluntary carbon market.

3.3.2 Beta regression

Beta regression aligns with the dependent variable, "Effectiveness", conceptualized as the ratio of retired credits to total issued credits within carbon offset projects, a measure reflective of carbon reduction. Beta-regression is a realistic model of its inherent design to handle data bounded within the [0,1] interval (Cribari-Neto & Zeileis, 2010). Unlike other regression techniques that may struggle with boundary values or require transformations that could distort the fundamental nature of the data, Beta regression maintains the integrity of the original scale, offering direct and interpretable coefficient estimates.

Beta regression stands out for its nuanced understanding of variance within proportional data, a critical advantage over other regression models (Cribari-Neto & Zeileis, 2010). It offers insights into the mean response and the precision of the data, factors that are particularly pertinent in environmental and economic research, where variables often exhibit skewed and heteroskedastic behaviour. In the context of the study, the Effectiveness variable, which measures the ratio of retired credits to total issued credits within carbon offset projects, is a natural candidate for beta regression due to its bounded nature. The effectiveness of these projects, conceptually defined as a proportion, must be analysed with a method that respects its intrinsic properties—namely, that it cannot exceed 1 or fall below 0. To appropriately model Effectiveness while avoiding the issues posed by the boundary values of 0 and 1, the data undergo a transformation before analysis. This transformation ensures that all effectiveness values strictly fall within the open interval (0,1), which is a requirement for the logit function used in the regression model. The adjustment formula applied for effectiveness is as follows:

$$AdjustedEffectiveness_i = \max(\epsilon, \min(Effectiveness_i, 1 - \epsilon))$$

Here, ϵ is a small constant set to 0.0001. This adjustment pushes any effectiveness values that are exactly 0 or 1 away from these boundaries, respectively, to $1-\epsilon$. Such an approach not only prevents issues during the computation of the logit but also respects the continuous nature of the beta distribution by avoiding the inclusion of the exact endpoints. The mathematical backbone of beta regression involves linking the mean of the beta-distributed variable, μ, to predictor variables through a logit function, as shown in the model. Additionally, in the context of the beta regression model, it's important to define and discuss the precision parameter ϕ, which represents the dispersion of the data around the expected mean. This parameter is used for understanding the variability and precision of the effectiveness estimates, as it inversely influences the variance of the distribution. A higher ϕ suggests less dispersion and more confidence in the predicted effectiveness values, making it a vital aspect of the model's diagnostics that can offer insights into the confidence levels of the effectiveness predictions.

The Beta model is specified as follows:

$$\mu_i = \beta_0 + \beta_1 * Scale_i + \beta_2 * Region_i + \beta_3 * Scope + \beta_4 * DevelopingDeveloped_i + \beta_5 * CarbonMechanism_i$$

where μ_i represents the expected proportion of "Effectiveness" of the *i-th* project, β_0 through β_5 are the parameters to be estimated.

This specification allows for the direct interpretation of how predictors affect the effectiveness on a logistic scale, thereby maintaining the integrity of the proportional data. The model is fitted using maximum likelihood estimation, enhancing its efficiency and the reliability of the inferences drawn from the data.

3.3.3 OLS regression

Pooled Ordinary Least Squares (OLS) regression serves as a foundational analytical tool in this thesis, providing a baseline for understanding the overall patterns and relationships within the dataset. This method estimates a linear regression model by minimizing the sum of the squares of the residuals, providing parameter estimates that are the best fit to the observed data (Woolridge, 2009). The dependent variable “Effectiveness” is analysed using OLS to estimate the average effects of various predictors across the entire dataset of carbon offset projects.

While Pooled OLS is broadly applicable and facilitates the straightforward computation of average effects, it is critical to acknowledge its inherent limitations, particularly when dealing with data that are bounded within the [0,1] interval, such as our “Effectiveness” variable. Traditional OLS assumes that error terms are normally distributed and exhibit constant variance (homoscedasticity) (Woolridge, 2009). However, these assumptions can be problematic in environmental economic data, which often display boundaries at 0 and 1 and may involve skewed distributions or heteroscedastic behaviour. To address these issues and ensure the robustness of the OLS results, the thesis employ diagnostic tests.

The OLS model is specified as follows:

$$Y_i = \beta_0 + \beta_1 * Scale_i + \beta_2 * Region_i + \beta_3 * Scope$$
$$+ \beta_4 * DevelopingDeveloped_i + \beta_5 * CarbonMechanism_i + \epsilon_i$$

where Y_i represents the “Effectiveness” of the *i-th* project, β_0 through β_5 are the coefficients to be estimated, and ϵ_i is the error term.

Despite its limitations, Pooled OLS provides insights into general trends and helps establish a benchmark for comparing the effectiveness of other more complex models tailored to bounded outcomes, such as Beta regression or Tobit models.

3.3.4 Tobit regression

Tobit regression is suited to this study’s analytical needs due to its design for handling censored dependent variables (Greene, 1999). Like the Beta regression, Tobit models are essential when outcomes are constrained within an interval, in this case, [0,1]. “Effectiveness” is conceptualized as a manifestation of an underlying latent variable. This latent variable represents the true, unobserved effectiveness that could, theoretically, take values beyond the observed [0,1] interval. The observed values are only recorded up to these bounds, meaning that any latent effectiveness below zero or above one is censored and observed at these boundary points. This specification is used because it acknowledges the possibility of intrinsic factors driving project effectiveness beyond the observable range, thereby providing a more nuanced and theoretically consistent approach to modelling. This fits well as projects can't take values that exceed 1.

The Tobit model is defined as follows:

$$Y_i^* = \beta_0 + \beta_1 * Scale_i + \beta_2 * Region_i + \beta_3 * Scope + \beta_4 * DevelopingDeveloped_i + \beta_5 * CarbonMechanism_i + \epsilon_i$$

$$Y_i = \begin{cases} 0 & if\ Y_i^* \leq 0 \\ Y_i^* & if\ 0 < Y_i^* < 1 \\ 1 & if\ Y_i^* \geq 1 \end{cases}$$

Where Y_i^* is the latent variable of "Effectiveness" for the *i-th* project, β_0 through β_5 are the coefficients to be estimated, and ϵ_i is the error term, assumed to be normally distributed.

By employing Tobit regression, the study accounts for the censored nature of the data. This method provides estimates for how various project factors, such as scale, region, scope, development status, and the presence of a carbon mechanism, influence the observed effectiveness of carbon offset projects.

4. Results

This section presents the findings of the study, which aims to explain the factors influencing the effectiveness of carbon offset projects within the Voluntary Carbon Market. Building upon the hypotheses outlined in Chapter 2, this analysis employs an approach that integrates quantitative methods and statistical techniques to explore the dynamics of VCM participation and performance across different regions and technologies. The analysis draws upon a wealth of data sourced from the Berkeley Voluntary Registry Offset Database, ensuring an empirical foundation. Statistical techniques such as comparative analysis, Beta regression, OLS, and Tobit models are employed to discern meaningful patterns and relationships within the dataset. By synthesizing theoretical insights with empirical findings, this study endeavours to offer valuable insights for stakeholders in the VCM, informing policy-making and strategic decision-making in the pursuit of sustainable environmental practices. The ensuing discussion in Chapter 5 will critically examine these results and their implications, providing an understanding of the VCM landscape and avenues for future research. There are supporting materials in Appendix B and C for the Comparative analysis and for the robustness of the regressions.

4.1 Comparative analysis

This section delivers a detailed analysis of the effectiveness of carbon offset projects, examining influences across scale, region, scope, development status, and carbon mechanism implementation with comparative analysis. It highlights how diverse factors, from environmental conditions to socio-economic variables, significantly shape project outcomes, offering critical insights for optimizing carbon offset strategies. In Appendix B, Table B.1, “Benchmarking Effectiveness”, and Table B.2, “Effectiveness Distribution Across Regions”, provide detailed statistical summaries of the data visualized in the respective sections. These tables display various statistical measures including the mean, minimum, first quartile (Q1), median, third quartile (Q3), maximum, and the total count of projects per category.

4.1.1 Benchmarking effectiveness

Figure 9 below shows the results effectiveness of carbon offset projects across multiple dimensions, including scale, region, scope, development status, and carbon mechanism implementation. These visual and numerical representations in Table 7 in the Appendix serve as a tool for analysing the distribution and variability of effectiveness within each category.

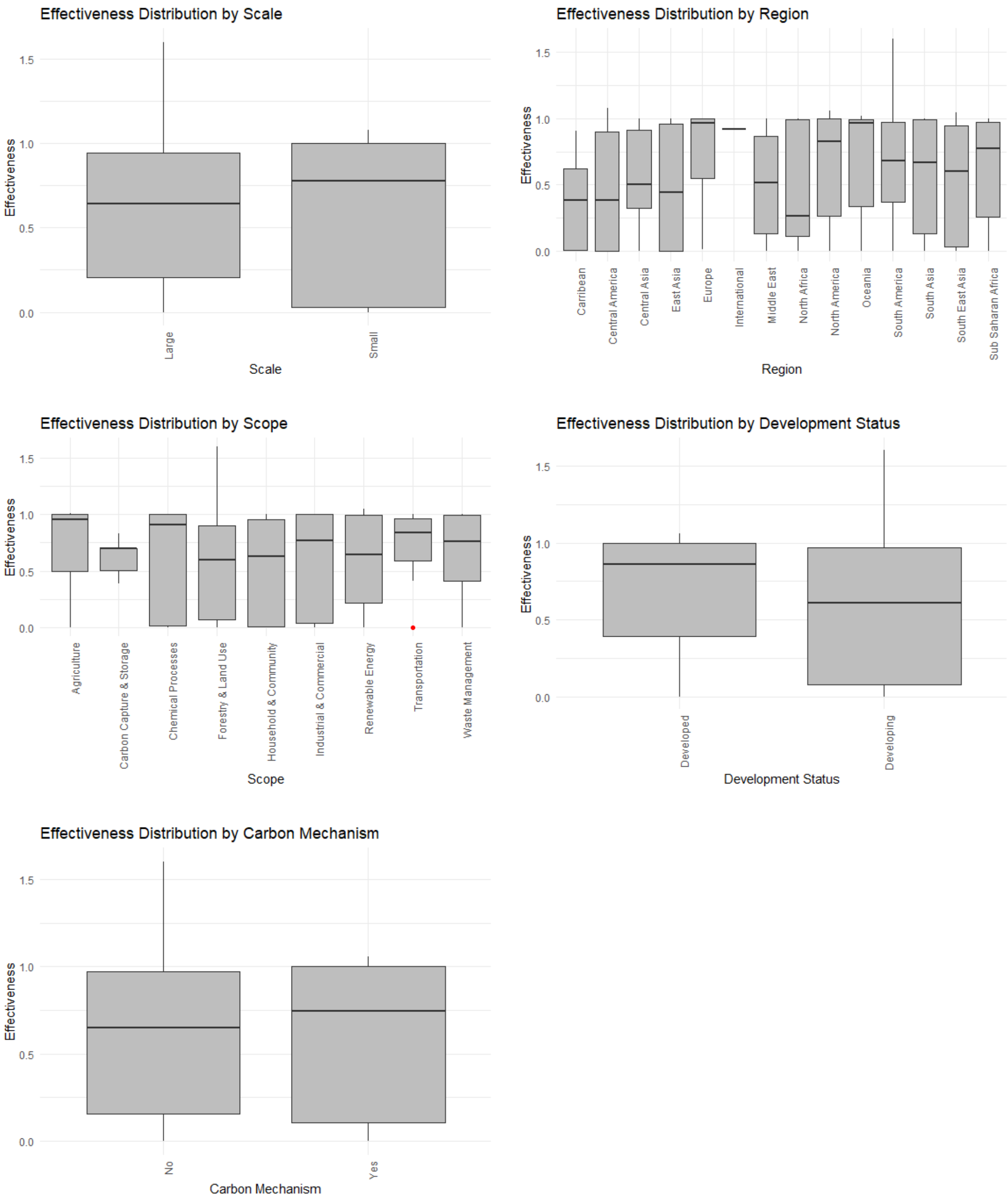


Figure 9 Effectiveness of carbon offset projects across multiple dimensions, including scale, region, scope, development status, and carbon mechanism implementation.

The analysis of carbon offset projects by scale reveals notable differences in effectiveness. Smaller projects, with a total of 2001 observed projects, have a median effectiveness of 0.778 and a mean of 0.596, suggesting that on average, they perform quite well. In contrast, larger projects, with 2000 observed projects, exhibit a slightly lower median effectiveness of 0.640 and slightly lower mean of 0.567. This pattern indicates that they generally show less variability in effectiveness. This finding underscore previous research from Castro &

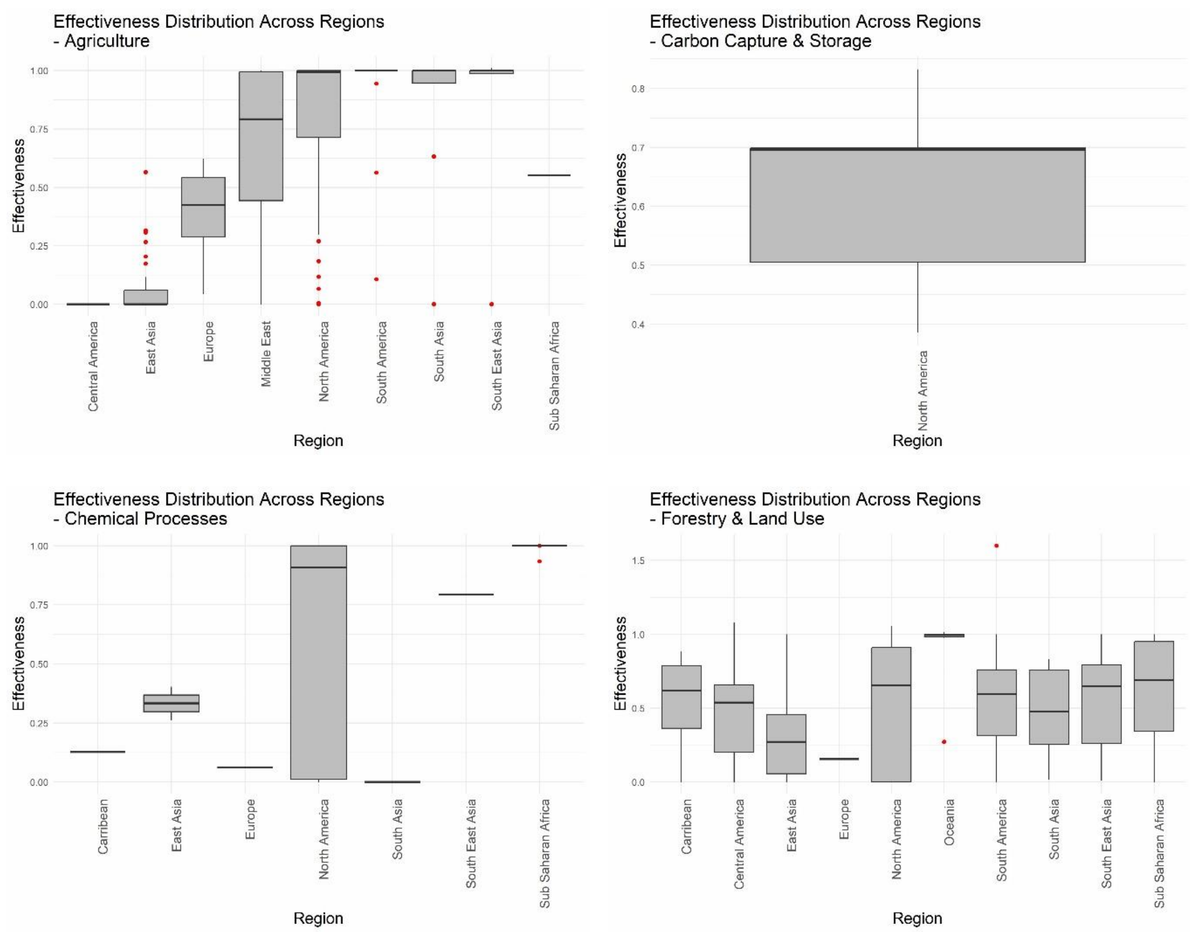
Michaelowa (2008) suggesting that smaller-scale projects might be more adaptable and capable of higher success rates under varying conditions. The regional analysis of project effectiveness reflects significant variations across different global areas, emphasizing the impact of diverse geopolitical and socio-economic environments. With regions like Europe (55 projects) and Oceania (14 projects) showing high mean and median effectiveness values of 0.762 and 0.966 for Europe, and 0.678 and 0.969 for Oceania, it’s evident that projects in these areas tend to perform well on average. However, in regions such as the Caribbean (11 projects) and Central America (53 projects), where the mean and median effectiveness is markedly lower at 0.360 and 0.384 for Caribbean, and 0.420 and 0.383 for Central America, challenges related to regulatory and economic factors might be impacting project outcomes.

Analysis of the various scopes reveals that renewable energy projects are the most numerous with 1391 projects. They have a mean and median effectiveness of 0.583 and 0.648, which indicates a good average performance. Agricultural projects (258 projects) and chemical processes (346 projects) show higher mean and median effectiveness values of 0.713 and 0.954 for Agricultural, and 0.607 and 0.912 for chemical processes. The development status of a region significantly affects project effectiveness. Developed regions, with 1122 projects, show a higher mean and median effectiveness of 0.677 and 0.861, reflecting the advantages of better technological and financial resources. Developing regions (2879 projects) have a lower mean and median effectiveness of 0.545 and 0.608. This stark contrast highlights the disparities in resource availability and infrastructure that can influence the average performance of projects in these areas. Lastly, the implementation of a carbon mechanism positively correlates with project effectiveness. Projects with a carbon mechanism (1963 projects) show a higher mean and median effectiveness of 0.596 and 0.743. In comparison, projects without a carbon mechanism (2038 projects) have a lower mean and median effectiveness of 0.568 and 0.651.

The initial findings from the analysis of carbon offset projects underscore the significance of scale, regional disparities, and developmental status in determining effectiveness. Smaller projects tend to perform better on average, suggesting higher adaptability and potential success, while larger projects display less variability in effectiveness. Regional variations are pronounced, with Europe and Oceania achieving high median effectiveness. The analysis also highlights the influence of a region’s development status on project success, with developed regions generally exhibiting higher effectiveness than their developing counterparts. Moreover, the presence of a carbon mechanism within projects correlates with improved effectiveness, emphasizing the benefits of structured environmental frameworks.

4.1.2 Effectiveness distribution across regions

The analysis presented in Figure 10 and Table 8 in Appendix B.2 provides an exploration of the effectiveness of carbon offset projects, dissecting outcomes across a spectrum of regions and scopes. This section delves into the variability of effectiveness in agriculture, carbon capture and storage (CCS), chemical processes, forestry, and land use, along with household and community initiatives, industrial and commercial activities, renewable energy, transportation, and waste management projects.



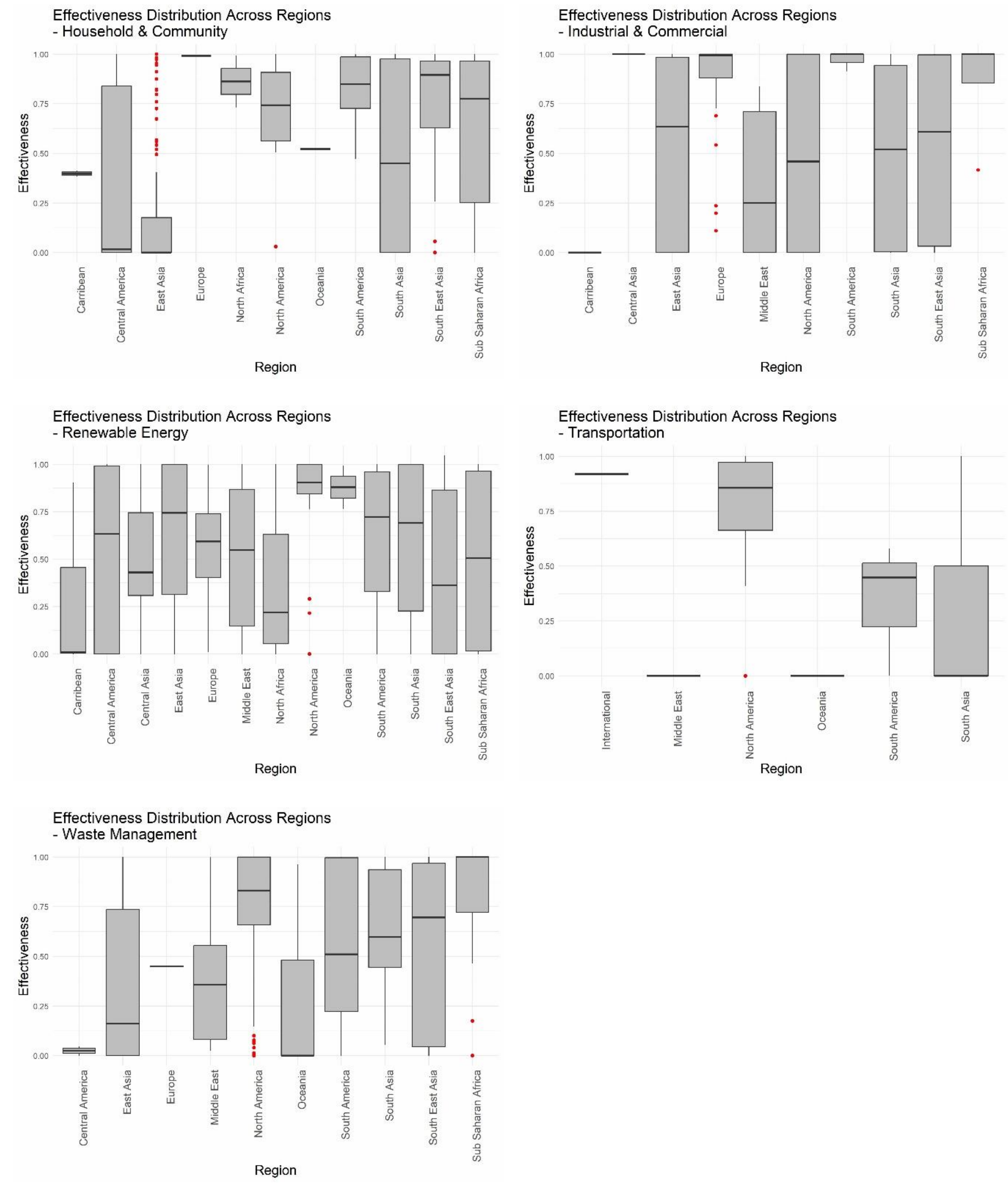


Figure 10 Effectiveness of carbon offset projects, dissecting outcomes across scopes for different regions.

Agriculture projects in North America shows a high mean and median effectiveness of 0.816 and 0.994 based on 185 projects, indicative of highly successful outcomes in this region. Conversely, East Asia, despite having fewer projects (32), exhibit significantly lower effectiveness, with mean and median values at or near zero. The scope of CCS is represented solely by North America, where the 5 projects analysed show a range of effectiveness from moderate to high (0.386 to 0.833), with a mean and median of 0.624 and 0.696. Almost all of the chemical process projects are located in North America with 332 projects out of 346. The region shows a high mean and median effectiveness of 0.604 and 0.907. In contrast, other regions like the Caribbean and Europe, despite having one project each, exhibit much lower effectiveness. Forestry and Land Use show a broad spread across many regions, with Oceania leading in terms of mean and median effectiveness of 0.893 and 0.995 across 7 projects. Regions like North America, South America and Sub-Saharan Africa show considerable numbers of projects (327, 76, and 50 respectively) with good median effectiveness, illustrating the potential for forestry and land use projects to achieve significant carbon offset outcomes in diverse ecological and geographical settings.

Sub-Saharan Africa stands out with 539 out of 899 projects in the scope Household & Community. It shows a decent mean and median of 0.621 and 0.776. The wide range of effectiveness across regions such as East Asia and Central America, where outcomes vary greatly (from 0 to 1.0 in East Asia across 129 projects), suggests that local factors heavily influence success rates. Industrial & Commercial reveals high effectiveness in regions such as Europe, South America, and Sub-Saharan Africa. Renewable energy projects located in Asia, with South Asia and East Asia showing a high mean and median effectiveness of 0.599 and 0.690 across 575 projects for South Asia, and 0.638 and 0.744 across 335 projects, suggest robust outcomes. However, Caribbean show lower effectiveness, reflecting potential regional challenges in harnessing renewable energy technologies. Transportation projects are located in North America (37 out of 45) and show a mean and median effectiveness of 0.800 and 0.857. Lastly, Waste Management projects shows good mean for most of the regions varying from 0.357 to 0.802 excluding Central America having two unsuccessful projects. This analysis of effectiveness for scope across regions underscores the impact of local conditions and sector-specific dynamics on the effectiveness of carbon offset projects, revealing insights within the Voluntary Carbon Market.

4.2 Regression results

This section of the thesis delves into an analysis using three Beta Regression, Pooled OLS, and Tobit regression. Each method offers insights and handles the data characteristics differently, thereby providing a framework for evaluating how various factors influence project outcomes. This analysis examines the residuals and diagnostics to assess the quality and appropriateness of each model. From Table 3 below the different regressions are presented, also in Appendix C in Table 9, 10, and 11 there are robustness tests of the regressions showing density of residuals, residuals vs Indices of observations, residuals vs. linear predictor, and QQ-plot.

Table 3 Regression results from Beta, Pooled OLS, and Tobit.

	Beta Regression	**Pooled OLS**	**Tobit**
(Intercept)	0.48 (0.15)***	0.72 (0.04)***	0.78 (0.06)***
ScaleSmall	0.17 (0.05)***	0.03 (0.01)*	0.07 (0.02)***
RegionCarribean	0.29 (0.43)	0.02 (0.13)	0.13 (0.19)
RegionCentral America	0.48 (0.25)	0.06 (0.07)	0.19 (0.11)
RegionCentral Asia	0.19 (0.52)	-0.03 (0.15)	0.05 (0.24)
RegionEast Asia	0.36 (0.14)*	0.01 (0.04)	0.11 (0.07)
RegionEurope	0.39 (0.19)*	0.08 (0.06)	0.09 (0.09)
RegionInternational	1.49 (1.36)	0.55 (0.39)	0.79 (0.58)
RegionMiddle East	0.46 (0.20)*	0.05 (0.06)	0.18 (0.09)
RegionNorth Africa	0.64 (0.49)	0.05 (0.14)	0.23 (0.21)
RegionOceania	0.34 (0.36)	0.11 (0.10)	0.17 (0.16)
RegionSouth America	0.89 (0.17)***	0.21 (0.05)***	0.40 (0.08)***
RegionSouth Asia	0.81 (0.18)***	0.15 (0.05)**	0.34 (0.08)***
RegionSouth East Asia	0.59 (0.19)**	0.13 (0.05)*	0.27 (0.09)**
RegionSub Saharan Africa	1.23 (0.18)***	0.28 (0.05)***	0.54 (0.08)***
ScopeAgriculture	-0.03 (0.11)	-0.03 (0.03)	0.01 (0.05)
ScopeCarbon Capture & Storage	-0.56 (0.62)	-0.15 (0.17)	-0.25 (0.26)
ScopeChemical Processes	-0.33 (0.11)**	-0.18 (0.03)***	-0.20 (0.05)***
ScopeForestry & Land Use	-0.50 (0.09)***	-0.16 (0.03)***	-0.24 (0.04)***
ScopeHousehold & Community	-0.72 (0.08)***	-0.15 (0.02)***	-0.31 (0.03)***
ScopeIndustrial & Commercial	-0.39 (0.11)***	-0.11 (0.03)***	-0.17 (0.05)***
ScopeTransportation	-0.43 (0.22)*	-0.08 (0.06)	-0.17 (0.10)
ScopeWaste Management	-0.20 (0.10)*	-0.06 (0.03)*	-0.09 (0.04)*
Developing_DevelopedDeveloping	-1.02 (0.13)***	-0.27 (0.04)***	-0.48 (0.06)***
Carbon_MechanismYes	0.20 (0.12)	0.06 (0.03)	0.10 (0.05)
Precision: (phi)	0.48 (0.01)***		
Log(scale)			-0.56 (0.02)***
Pseudo R2	0.08		
Log Likelihood	7332.95		-3599.96
Num. obs.	4001	4001	
R2		0.07	
Adj. R2		0.06	
AIC			7251.92
BIC			7415.58
Deviance			5424.93
Total			4001
Left-censored			689
Uncensored			2494
Right-censored			818
Wald Test			818

***p < 0.001; **p < 0.01; *p < 0.05

4.2.1 Beta regression

The Beta regression analysis offers a detailed assessment of the effectiveness of carbon offset projects with North America and Renewable Energy serving as baseline categories for regions and scopes, respectively. The intercept coefficient (0.48, $p < 0.001$) indicates a significant base level of effectiveness in North American renewable energy projects. The analysis further reveals that smaller-scale projects are markedly more effective, with a coefficient of 0.17 ($p < 0.001$), suggesting that their adaptability and localized focus contribute positively to their outcomes. Regional analysis highlights that regions like South America, South Asia, and Sub Saharan Africa exhibit significantly higher effectiveness than North America, with coefficients of 0.89, 0.81, and 1.23 respectively, all at $p < 0.001$. This suggests that despite geographical and socio-economic differences, certain regions are achieving superior outcomes in carbon offset projects. Conversely, scopes such as Household & Community, Forestry & Land Use, and Chemical Processes show significant negative deviations from Renewable Energy, with coefficients of -0.72, -0.50, and -0.33 respectively, indicating specific challenges that reduce their effectiveness.

These findings are underpinned by robust diagnostic checks which confirm the model’s reliability in interpreting these complex interactions. The density of residuals suggests heterogeneity within the data, while plots of residuals against indices and predictors show no significant anomalies, affirming the model’s adequacy. Additionally, the Developing status shows a strong negative impact on effectiveness, with developing regions exhibiting significantly lower effectiveness, highlighted by a coefficient of -1.02 ($p < 0.001$). This underscores the critical challenges faced in enhancing carbon offset effectiveness in less developed regions. The carbon mechanism variable, though not statistically significant, suggests a positive influence on project effectiveness. Together, these insights provide a nuanced understanding of how regional and scope-specific factors, along with development status and project scale, influence the effectiveness of carbon offset initiatives.

4.2.2 OLS regression

The OLS regression analysis offers an expansive overview of the effectiveness of carbon offset projects, utilizing North America and Renewable Energy as baseline categories for regions and scopes respectively. The intercept from the OLS model at 0.72 ($p < 0.001$) suggests that North American renewable energy projects represent a significantly effective baseline from which other regions and scopes diverge. While the coefficient for small-scale projects is positive at 0.03 ($p < 0.05$), it indicates a less pronounced effect compared to the Beta regression, highlighting the relatively modest influence of project scale on effectiveness within the OLS framework. Regional comparisons reveal that while areas like South America, South Asia, and Sub Saharan Africa are more effective than North America, with coefficients of 0.21, 0.15, and 0.28 respectively, all showing statistical significance, the effects are generally more tempered compared to those observed in the Beta regression model.

The analysis of scopes shows that, similar to the Beta model, all specific project scopes exhibit negative impacts relative to Renewable Energy. The most notable are Forestry & Land Use and Household & Community, with coefficients of -0.16 and -0.15 respectively, both significant at $p < 0.001$. This highlights that, even within a simpler linear framework, these project types face inherent challenges that reduce their effectiveness compared to renewable energy initiatives. Furthermore, the robustness of the OLS model's findings, though generally reliable for broad trend analysis, does not encapsulate the complexity of boundary constraints or distributional nuances as effectively as the Beta regression. The R^2 value of 0.07 indicates a moderate explanatory power of the model, suggesting that while OLS provides valuable insights into general trends and relative differences between categories, it may overlook finer-grained interactions and censored data characteristics that are better captured by models specifically tailored to bounded outcomes, like the Beta regression or Tobit models.

4.2.3 Tobit regression

The Tobit regression analysis, tailored for handling the censored nature of the effectiveness variable in carbon offset projects, also utilizes North America and Renewable Energy as baseline categories for regions and scopes. The intercept from the Tobit model, at 0.78 ($p < 0.001$), indicates a high base level of effectiveness in projects from these baseline categories, demonstrating their prominence as benchmarks in this field. Similar to the Beta regression, the Tobit model's findings underscore the significance of small-scale projects, with a coefficient of 0.07 ($p < 0.001$), suggesting their higher effectiveness compared to larger projects, albeit with a subtler influence compared to the more expressive Beta model results. This model's nuanced handling of censored data allows for a precise estimation of effects near the boundaries of the effectiveness range.

Regionally, the Tobit model reveals that South America, South Asia, and Sub Saharan Africa outperform the North American baseline, with coefficients of 0.40, 0.34, and 0.54 respectively, all statistically significant at $p < 0.01$. These regions exhibit robust positive deviations from the baseline, pointing to particularly effective regional strategies or conditions that surpass those prevalent in North America. In the scope analysis, negative coefficients for scopes like Household & Community (-0.31, $p < 0.001$), Forestry & Land Use (-0.24, $p < 0.001$), and Chemical Processes (-0.20, $p < 0.01$) illustrate challenges specific to these project types, which hinder their effectiveness relative to Renewable Energy projects. The detailed breakdown by the Tobit model not only aligns with findings from the Beta regression but also highlights the model's capability to handle latent variables effectively, providing deeper insights into the distributional aspects of effectiveness. Moreover, the model's diagnostics, as evidenced by its significant coefficients across multiple regions and scopes, reveal a pattern of effectiveness that is markedly influenced by geographical and project-specific factors. The log likelihood and Wald test statistics further solidify the model's robustness and the reliability of its estimates.

5. Discussion

In the discussion section, the findings from Chapter 4 are integrated with the theoretical framework and empirical review from Chapter 2, with each hypothesis analysed in its own section. The results are first summarized, and then compared with previous studies to highlight similarities and differences, enhancing understanding of the outcomes. This comparative analysis explores the theoretical implications and practical applications of the findings, while also assessing hypothesis-specific limitations in the dataset and methodology that may affect the robustness and generalizability of the results. The discussion concludes by synthesizing how the hypotheses inform the central research question and detailing the study's contribution to the academic field. It also reviews the general limitations impacting the internal and external validity, framing the scope and applicability of the research and suggesting directions for future studies.

5.1 Scale

In exploring the hypothesis that project scale influences the effectiveness of carbon offset projects, the results from Chapter 4 provide compelling insights. Smaller-scale projects demonstrate higher mean and median effectiveness (0.596 and 0.778) compared to their larger counterparts (0.567 and 0.640). This finding suggests that smaller projects, due to their adaptability and potential for tailored approaches, may better address specific environmental and community needs, leading to more effective carbon sequestration or emission reductions. The theoretical underpinnings from Chapter 2 support this observation, highlighting that smaller projects can be more agile, integrating local knowledge and community participation more effectively than larger projects. This is in line with Castro & Michaelowa's (2008) findings, which suggested that smaller-scale projects often yield better outcomes in terms of CERs issuance, especially in less industrialized regions where large-scale projects may face bureaucratic and infrastructural barriers.

However, contrasting these findings with broader literature presents a nuanced picture. While smaller projects appear more effective in this dataset, literature such suggests that larger projects might benefit from economies of scale, potentially leading to more significant impacts on carbon reduction in the aggregate. This discrepancy may be attributed to the diverse methodologies and regional focuses of these studies, suggesting that the effectiveness of project scale might vary significantly across different environmental and regulatory contexts.

A critical examination of the dataset and methodology used to support this hypothesis reveals potential limitations. The classification of project scale might overlook the complexity of project operations and their interdependencies with other factors such as scope, region, and the presence of a carbon mechanism. For instance, the effectiveness of small projects might be overestimated if these projects are predominantly located in regions with more favourable environmental policies or technological advancements. Further, while the results align with some aspects of the existing literature, they diverge in others, underscoring the importance of context in evaluating the effectiveness of carbon offset projects. The broader implications of these findings suggest that policymakers and practitioners should consider supporting a mix of project scales within the carbon market, tailoring strategies to the specific strengths and needs of each project type and region.

This analysis not only reaffirms the significance of project scale in determining the effectiveness of carbon offset initiatives but also enhances our understanding of how different factors interact within the voluntary carbon market. The analysis supports the hypothesis that the scale of carbon offset projects significantly influences their effectiveness. Smaller-scale projects consistently show higher effectiveness, suggesting that their adaptability is better in achieving successful carbon mitigation outcomes. This finding validates the theoretical expectation that smaller initiatives can more effectively integrate into local contexts, thereby enhancing their overall impact on carbon reduction. Such results underscore the need for policies that support the diversity of project scales, particularly encouraging the development and implementation of smaller, community-focused projects that can operate efficiently under varied environmental and socio-economic conditions.

5.2 Region

The role of regional disparities in influencing the effectiveness of carbon offset projects can be contextualized within the broader scope of VCMs as highlighted in the literature. The literature review establishes a theoretical framework where regional variations are not only expected but are essential in shaping the outcomes of carbon offset projects. Key studies, such as those discussed by Battocletti, Enriques, & Romano (2023), emphasize the strategic participation of significant emitters like energy companies in developing regions, which could explain the higher effectiveness noted in certain less-developed regions due to targeted carbon offset initiatives. Moreover, the nuances of regional effectiveness align with the insights provided by Spilker & Nugent (2022) and the IPCC reports, which underline the urgent need for region-specific strategies to combat climate change effectively. These strategies are often influenced by the region's socio-economic and political frameworks, which can accelerate or hinder the implementation of effective carbon offsetting projects. For instance, the literature suggests that regions with stringent environmental policies or advanced technological capabilities might demonstrate higher effectiveness in their carbon-offsetting projects due to better implementation and adherence to international standards.

The regional analysis of carbon offset project effectiveness reveals significant geographical disparities, affirming the hypothesis that regional factors influence the success of these initiatives. The Beta regression results show South America, South Asia, and Sub-Saharan Africa with coefficients of 0.89, 0.81, and 1.23, respectively, all significant at $p < 0.001$, indicating these regions exhibit substantially higher effectiveness compared to North America. These regions' robust performance could be attributed to specific regional initiatives or adaptive strategies to local environmental conditions, which are more effective in carbon mitigation. Conversely, regions such as the Caribbean and Central America display notably lower effectiveness, with mean and median effectiveness values of 0.360 and 0.384 for Caribbean, and 0.420 and 0.383 for Central America. This underperformance could be linked to challenges such as less developed regulatory frameworks, economic constraints, or lower technological adoption, which are critical factors as discussed in environmental economics literature.

However, the analysis faces limitations due to high Variance Inflation Factor (VIF) values noted for regional variables, suggesting potential multicollinearity issues that could influence the reliability of these estimates. High VIF values, particularly for the region (ranging from 84.130 to 89.758 across different regression models), indicate a significant overlap in the variance explained by regional variables, which complicates isolating the specific impact of one region from another. This statistical overlap might cloud the true effects of individual regional characteristics on project effectiveness. Despite these statistical challenges, the results support the hypothesis, highlighting the critical role of geographical differences in determining the effectiveness of carbon offset projects. These findings align with theoretical insights suggesting that regional environmental policies, economic stability, and technological capacities are essential in shaping the outcomes of carbon offset initiatives.

In conclusion, while the hypothesis that regional factors significantly impact the effectiveness of carbon offset projects is supported, the interpretation of these results must consider the high multicollinearity among regional predictors. Addressing these methodological challenges in future studies will be important for clearer and more definitive insights into the regional dynamics of carbon offset effectiveness.

5.3 Scope

The examination of the scope of carbon offset projects reveals how different project types variably contribute to carbon reduction efforts, underscoring the complexity of achieving effective climate action across varied environmental and technological contexts. In the empirical analysis, certain scopes like Household & Community, Forestry & Land Use, and Chemical Processes are shown to have less effectiveness compared to Renewable Energy, which serves as the baseline. For instance, the Beta regression model illustrates negative coefficients for these scopes. A negative coefficient on the value of μ in the regression analysis indicates a negative relationship between the independent variable and the dependent variable, meaning an increase in the independent variable leads to a decrease in the project's effectiveness. For example, compared to the baseline category Renewable Energy, a negative coefficient for other project types such as Household & Community or Forestry & Land Use indicates that these projects are generally less effective than renewable energy projects. Specifically, Household & Community projects have a coefficient of -0.72 ($p < 0.001$), Forestry & Land Use at -0.50 ($p < 0.001$), and Chemical Processes at -0.33 ($p < 0.01$). These findings suggest that despite their potential benefits, these project types face inherent operational and environmental challenges that may hinder their overall effectiveness.

The literature offers several explanations for these findings. Studies like those by Bomfim et al. (2022) suggest that while projects like reforestation can sequester carbon effectively and provide biodiversity benefits, their success greatly depends on local conditions and management practices, which can vary widely. Similarly, the variable effectiveness of renewable energy projects highlighted in the regression analysis, where they appear more successful in comparison to other scopes, aligns with the literature emphasizing the rapid advancement and support for renewable technologies globally. Furthermore, the differences in effectiveness across scopes could also be linked to the scale and integration of projects within local economic and policy frameworks, as discussed in studies by Fujii et al. (2024). These factors are important in understanding why some scopes perform better than others, emphasizing the need for tailored strategies that consider the unique challenges and opportunities within each scope.

The analysis also highlights high variability in effectiveness within scopes, as demonstrated by the wide interquartile ranges observed in the data. For example, while some sectors like Renewable Energy show a mean and median effectiveness of 0.583 and 0.648, suggesting moderate success, sectors like Waste Management and Transportation exhibit a broader range of outcomes, indicating inconsistencies in project implementation and effectiveness. In conclusion, the hypothesis that the effectiveness of carbon offset projects varies significantly across different project scopes is supported by both the empirical data and the literature. The findings emphasize the need for sector-specific approaches in policy and project design to enhance the effectiveness of carbon offset projects. These strategies should account for the inherent challenges and potentials of each scope to optimize their contribution to carbon reduction efforts within the VCM.

5.4 Developing status

Knowing the differences in the efficacy of carbon offset projects between developed and developing areas depends on the examination of developing status within the context. The empirical data from the study reveal significant differences in project outcomes based on the development status of the host country, which can be contextualized through the lens of the broader theoretical framework and empirical studies discussed earlier. From the regression analysis, the developing status variable shows a negative effect on the effectiveness of carbon offset projects. Specifically, the Beta regression indicates a coefficient of -1.02 ($p < 0.001$), highlighting that projects in developing regions exhibit substantially lower effectiveness compared to their developed counterparts. This is consistent with empirical observations where developed countries show a higher mean and median effectiveness of 0.677 and 0.861 for developed countries compared to 0.545 and 0.608 in developing countries. These findings are statistically significant and echo the challenges faced by developing countries in implementing and sustaining effective carbon offset initiatives due to constraints like limited technological access, financial resources, and institutional support.

The literature reviewed in Chapter 2 provides several insights that align with these empirical findings. For instance, studies suggest that the effectiveness of environmental policies, including those related to carbon offsetting, is often compromised in developing regions due to weaker regulatory frameworks and infrastructural deficiencies (Castro & Michaelowa, 2008). Furthermore, the work by Fujii et al. (2024) underscores the variability in the success of carbon projects across different geographical settings, influenced by regional capacities and policy environments. Moreover, the differences in effectiveness based on developing status also resonate with the broader issues discussed in the literature concerning the distribution of benefits and burdens in global environmental governance. Developed regions often have better-established mechanisms for project validation and more robust market structures, which facilitate higher effectiveness in carbon offsetting efforts (Spilker & Nugent, 2022). In contrast, developing regions, despite potentially benefiting more from sustainable development co-benefits of carbon offset projects, face numerous hurdles that limit their effectiveness.

The analysis also considers the high VIF for the region, which indicates multicollinearity in the regression models, particularly affecting the precision and reliability of estimates related to regional effects. This could be attributed to the overlapping influences of regional characteristics on project outcomes, which complicate the isolation of the specific impacts of development status. Resolving these methodological issues will help to improve future research and increase the applicability of the results.

In conclusion, the hypothesis that the effectiveness of carbon offset projects varies significantly between developed and developing regions is supported by both empirical data and theoretical insights. The results underscore the need for tailored strategies that consider the specific challenges and opportunities in developing regions to enhance their capacity for effective carbon management. This involves not only increased financial and technological support but also the development of governance frameworks that can accommodate the unique socio-economic contexts of these regions.

5.5 Carbon Mechanism

The exploration of the impact of carbon mechanisms on the effectiveness of carbon offset projects sheds light on how regulatory frameworks influence project outcomes. The regression analysis from the study provides a clear quantitative foundation to assess this impact. From the statistical data, the presence of a carbon mechanism in the region of project implementation shows a positive but less significant impact on project effectiveness. In the Beta regression analysis, the coefficient for carbon mechanism implementation is 0.20 ($p > 0.05$), indicating a positive association, although not statistically significant at conventional levels. This suggests that while there is a trend towards better project performance with carbon mechanisms, the influence is not as robust as some might anticipate. The mean and median effectiveness for projects within regions that have implemented carbon mechanisms is higher (0.596 and 0.742) compared to those without such mechanisms (0.568 and 0.651), as noted in the benchmarking effectiveness results. These findings underscore a nuanced effect where carbon mechanisms potentially contribute to better project outcomes but are influenced by additional regional or project-specific factors.

The theoretical framework discussed in Chapter 2, alongside the empirical reviews, supports the notion that carbon pricing mechanisms, like carbon taxes or cap-and-trade systems, play a role in shaping project outcomes. For instance, the literature posits that these mechanisms can provide financial incentives for reducing emissions and promote investment in carbon reduction technologies (Fujii, et al., 2024). This aligns with the empirical observation that carbon mechanisms can enhance the effectiveness of carbon offset projects by providing a structured financial and regulatory environment that supports project implementation and compliance. Furthermore, studies like those conducted by Streck (2021) highlight the growth in corporate engagement with VCMs as entities seek to meet climate commitments under increasing regulatory and market pressures. This context suggests that carbon mechanisms not only facilitate direct project financing but also signal to the market a formalized commitment to emission reductions, thereby attracting more substantial private investment and participation in carbon offsetting initiatives.

However, the modest statistical significance of carbon mechanisms in enhancing project effectiveness as revealed by the regression analysis suggests that merely having a carbon pricing policy is not sufficient to ensure project success. This could be attributed to the variability in how these mechanisms are implemented and their interaction with other local factors such as economic conditions, public acceptance, and the overall regulatory environment. In conclusion, while the hypothesis that projects in regions with established carbon pricing mechanisms are more effective than those without such mechanisms receives some empirical support, the findings are nuanced. The positive but statistically insignificant impact points to the potential of carbon mechanisms to enhance project effectiveness, yet also to the limitations of these policies when considered in isolation.

Contribution

The importance of this study lies in its potential to inform corporate investment in quality carbon offset projects, important for Net Zero transition plans. By analysing the VCM dynamics, it fills gaps in existing literature, providing insights into the efficacy of carbon credit transactions. This research aids companies and policymakers in understanding market mechanisms, contributing to effective climate action and guiding the development of robust, efficient carbon markets for global emissions reduction efforts. One of the principal contributions of this research lies in its analysis of how different factors influence the performance and participation in VCMs, thereby providing a more ore granular understanding that goes beyond existing studies which have predominantly focused on broad trends without delving into the interplay of these multifaceted influences. By employing a regression analysis and integrating these with empirical benchmarking, this study has systematically quantified the relative impacts of project scale, region, developmental status, and the presence of carbon mechanisms, offering new insights into the structural and operational dynamics of carbon offset initiatives.

Additionally, this thesis advances the academic discourse on carbon offsetting by challenging and refining the hypotheses associated with the effectiveness of carbon offset projects. It examines the assumption that certain regional and technological conditions inherently lead to more successful carbon offset outcomes, providing a nuanced perspective that acknowledges the complex interdependencies between policy frameworks, market mechanisms, and project execution. This investigation not only enriches the theoretical framework surrounding carbon markets but also offers practical implications for policymakers and stakeholders in the environmental sector. By identifying specific factors that enhance or hinder project effectiveness, the research provides a basis for targeted improvements in the design and regulation of VCMs, aiming to optimize their contribution to global carbon reduction goals. This is important as the demand for effective climate action mechanisms continues to grow in response to the urgent need for substantial and sustained reductions in greenhouse gas emissions globally.

Future research should delve deeper into quantitative methodologies that leverage data to unearth primary insights into the effectiveness of carbon offset projects. By focusing on data-driven approaches, researchers can enhance our understanding of the underlying drivers and factors that influence project outcomes. This exploration could include advanced statistical models to analyse datasets, allowing for more precise and predictive insights. Additionally, future studies could integrate comparative analyses across different regions and project types to identify and model variability in effectiveness. Such research would not only refine the existing theoretical frameworks but also contribute practical solutions and strategies to improve the implementation and management of carbon offset initiatives.

Limitations

The limitations of this study are important for interpreting its findings and understanding the scope within which these findings can be generalized. One of the primary limitations relates to the inherent challenges in establishing causality within the complexities of the VCM. Although the study designs its hypotheses and employs statistical methods to analyse the impact of various factors on the effectiveness of carbon offset projects, it is inherently limited by the observational nature of the data. This restricts the ability to definitively ascertain causal relationships, as the correlations observed may be influenced by unmeasured confounding variables or by the specificities of the data set that may not apply universally.

Another significant limitation is the potential for selection bias, which could affect the generalizability of the findings. The study relies on data from specific carbon registries, which may not fully represent the global landscape of carbon offset projects. Projects included in these registries might be those that have successfully passed certain quality checks or that were more likely to be documented and registered, possibly excluding smaller, less formal, or less successful initiatives. This selection could skew results towards more positive outcomes, thereby inflating the perceived effectiveness of carbon offset projects across different regions and scopes.

The study also faces challenges related to the potential for model overfitting and multicollinearity, especially given the complex interdependencies between the numerous variables examined. This is particularly evident in the high VIF observed for the variable region, which suggests substantial multicollinearity that could distort the estimated effects of the variable on the effectiveness of carbon offset projects. Such statistical concerns may complicate the interpretation of the regression results, leading to potential misestimations of the impacts of certain factors.

Additionally, the scope of this study is limited by the static nature of its data, which captures the status of projects at specific points in time without considering the dynamic aspects of project development and long-term sustainability. Carbon offset projects evolve over time, and their effectiveness can be impacted by changes in policy, technology, and environmental conditions that are not captured in a static dataset. This temporal limitation may prevent the study from fully understanding how the effectiveness of projects changes in response to ongoing environmental and economic shifts.

Lastly, the external validity of the study may be compromised by its focus on specific types of carbon offset projects and particular geographical locations. While the findings provide valuable insights into the factors influencing project effectiveness, they may not be universally applicable across all types of carbon offset projects or all geographical contexts. Different regions may have unique environmental, economic, and regulatory landscapes that significantly influence the outcomes of carbon offset projects in ways that are not fully captured by this study.

Despite these limitations, this thesis contributes to the broader understanding of the effectiveness of carbon offset projects and provides a foundation for future research to build upon. It highlights the need for more dynamic, comprehensive, and longitudinally-focused studies to better capture the evolving nature of carbon offset projects and their impacts on global carbon reduction efforts.

6. Conclusion

In this study, I explore the factors influencing the effectiveness of carbon projects within the Voluntary Carbon Market (VCM). The context of this thesis is set against a backdrop of increasing global emphasis on sustainable practices and carbon neutrality goals. As nations and corporations strive to reduce their carbon footprints, the VCM has become a critical component in the broader strategy to mitigate climate impact. However, scepticism about the efficacy and integrity of carbon offset projects persists, fuelled by concerns over the actual environmental benefits and the transparency of carbon trading practices. This doubt, while often rooted in isolated instances of failure or mismanagement, underscores the need for an understanding of the diverse factors that contribute to the success or failure of these initiatives. By dissecting the VCM through an analytical lens, this thesis aims to shed light on the complex interactions between regional characteristics, technological advancements, and project outcomes, moving beyond anecdotal evidence to provide a structured evaluation of the market's function and its role in global environmental strategy.

To examine the complexities within the VCM, I developed hypotheses aimed at unravelling the interplay between geographical and technological factors influencing the effectiveness of carbon offset projects. These hypotheses are rooted in the foundational theories of environmental economics and carbon market dynamics, which suggest that both regional characteristics and technological advancements shape project outcomes. Despite the theoretical framework, the multifaceted nature of market participation and project success presents challenges in pinpointing the precise drivers of effectiveness. To address these challenges, my research incorporates an analytical scope, integrating both sector-specific dynamics and regional environmental policies to assess their impact on the VCM. Given the variability inherent in such a market, my study strives to move beyond simple causal assertions, offering instead a detailed depiction of the VCM's operational intricacies and their implications for global carbon offset strategies.

The study investigates the impact of project scale and regional development status by leveraging data-driven methodologies. This begins with a statistical analysis where I map out investment characteristics across different scales and regions, drawing from datasets such as the Berkeley Voluntary Registry Offset Database. This method allows for an empirical assessment of the scale at which projects operate, distinguishing between large-scale and small-scale projects, and their varied success rates in developed versus developing regions. Subsequently, I broaden the analytical framework by incorporating econometric models to quantify and analyse the effectiveness of carbon offset projects. This part of my analysis involves constructing regression models that integrate a range of variables capturing regional development, technological deployment, and carbon pricing mechanisms. By applying methods such as Beta, Pooled OLS, and Tobit regression, I test the relationships posited by the hypotheses, providing an examination of how different variables influence project outcomes.

Applying the methodologies detailed in this thesis, it becomes apparent that the dynamics within the Voluntary Carbon Market exhibit distinct regional and project-scale variabilities that could potentially align with broader economic or environmental strategies. Specifically, my findings underscore that projects in developed regions and those utilizing carbon mechanisms demonstrate notably higher effectiveness in carbon offsetting compared to their counterparts in developing regions or those without such mechanisms. Moreover, the analysis partially supports the hypothesis that larger-scale projects tend to be more effective, though these findings are not uniformly conclusive across all tested models.

Despite identifying some patterns that suggest strategic alignment of projects within certain frameworks, these observations cannot be definitively interpreted as evidence of a deliberate or cohesive global strategy driving these disparities. The theoretical landscape is replete with alternative explanations that could account for the observed variabilities in project effectiveness, ranging from economic disparities to technological accessibility in different regions. Empirically, the challenge of endogeneity, arising from potential omitted variable biases and the issues of simultaneity and reverse causality, necessitates cautious interpretation of the results.

While the results show patterns, such as the significant impact of projects in areas with established carbon mechanisms, they do not definitively support the initial hypotheses of this study. However, these findings do contribute to a nuanced understanding of the VCM, illustrating how different factors influence project outcomes. This contribution is significant considering the previous reliance on aggregated and potentially biased data in the field. While my analysis does not resolve all methodological challenges or answer all questions regarding the strategic dimensions of carbon offset projects, it offers a refined empirical foundation from which future research could further explore these complex dynamics. In this sense, the thesis represents a step forward in the direction of understanding the complex elements influencing the efficacy of carbon offset programs in the global setting of climate change mitigation.

7. References

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8. Appendix

A. Dataset information

A.1 Regions with developing status and carbon mechanism

*Table 4 Region breakdown with countries including development status and carbon mechanism inclusion. *Countries that appears in several regions.*

Region	Country	Developed Country	Carbon Mechanism
Carribean	Aruba	No	No
	Bahamas	No	No
	Belize	No	No
	Dominican Republic	No	No
	Haiti	No	No
	Suriname	No	No
Central America	Costa Rica	No	No
	El Salvador	No	No
	Guatemala	No	No
	Honduras	No	No
	Nicaragua	No	No
	Panama*	No	No
Central Asia	Kazakhstan	No	Yes
	Russia	Yes	No
	Tajikistan	No	No
	Turkmenistan	No	No
	Uzbekistan	No	No
East Asia	China	No	Yes
	Japan	Yes	Yes
	Mongolia	No	No
	South Korea	Yes	Yes
	Taiwan	No	No
Europe	Albania	Yes	Yes
	Austria	Yes	Yes
	Bulgaria	Yes	Yes
	Estonia	Yes	Yes
	France	Yes	Yes
	Georgia	No	Yes
	Germany	Yes	Yes
	Greece	Yes	Yes
	Iceland	Yes	Yes
	Italy	Yes	Yes
	Kosovo	No	Yes
	Latvia	Yes	Yes
	Lithuania	Yes	Yes
	Netherlands	Yes	Yes
	North Macedonia	Yes	Yes
	Romania	Yes	Yes
	Serbia	Yes	Yes
	Spain	Yes	Yes
	Switzerland	Yes	Yes
	United Kingdom	Yes	Yes
International	International	No	No
	Greece	Yes	No
Middle East	Bahrain	No	No
	Cyprus	Yes	No
	Djibouti*	No	No

	Egypt*	No	No
	Iraq	No	No
	Israel	Yes	No
	Jordan	No	No
	Oman	No	No
	Saudi Arabia	No	No
	Syria	No	No
	Timor-Leste*	No	No
	Turkey	No	No
	United Arab Emirates	No	No
North Africa	Egypt*	No	No
	Morocco	No	No
	Sudan	No	No
	Tunisia	No	No
North America	Canada	Yes	Yes
	Mexico	No	Yes
	New Zealand*	Yes	Yes
	United States	Yes	Yes
Oceania	Australia	Yes	Yes
	Fiji	No	No
	New Caledonia	No	No
	New Zealand*	Yes	Yes
	Papua New Guinea	No	No
South America	Argentina	No	Yes
	Bolivia	No	No
	Brazil	No	No
	Chile	No	Yes
	Columbia	No	Yes
	Ecuador	No	No
	Panama*	No	No
	Paraguay	No	No
	Peru	No	No
	Uruguay	No	Yes
Southeast Asia	Cambodia	No	No
	Indonesia	No	Yes
	Laos	No	No
	Malaysia	No	No
	Myanmar	No	No
	Philippines	No	No
	Singapore	No	Yes
	Thailand	No	No
	Timor-Leste*	No	No
	Vietnam	No	No
Sub Saharan Africa	Angola	No	No
	Benin	No	No
	Botswana	No	No
	Burkina Faso	No	No
	Burundi	No	No
	Cameroon	No	No
	Central African Republique	No	No
	Chad	No	No
	Comoros	No	No
	Côte d'Ivoire	No	No
	Djibouti*	No	No
	DRC	No	No
	Eritrea	No	No
	Ethiopia	No	No

	Gambia	No	No
	Ghana	No	No
	Guinea-Bissau	No	No
	Kenya	No	No
	Lesotho	No	No
	Liberia	No	No
	Madagascar	No	No
	Malawi	No	No
	Mali	No	No
	Mauritania	No	No
	Mauritius	No	No
	Mayotte	No	No
	Mozambique	No	No
	Namibia	No	No
	Niger	No	No
	Nigeria	No	No
	Republic of Congo	No	No
	Rwanda	No	No
	Senegal	No	No
	Sierra Leona	No	No
	Somalia	No	No
	South Africa	No	Yes
	Tanzania	No	No
	Togo	No	No
	Uganda	No	No
	United Arab Emirates*	No	No
	Zambia	No	No
	Zimbabwe	No	No

A.2 Scope breakdown

Table 5 Breakdown of Scope with technology type.

Emission reduction, removal, and mixed Scope	Type
Agriculture	Bundled Compost Production and Soil Application, Compost Addition to Rangeland, Feed Additives, Improved Irrigation Management, Manure Methane Digester, Nitrogen Management, Rice Emission Reductions, Solid Waste Separation, Sustainable Agriculture
Carbon Capture and Storage (CCS)	Carbon Capture & Enhanced Oil Recovery, Carbon Capture in Cement, Carbon Capture in Plastic
Chemical Processes	Advanced Refrigerants, HFC Refrigerant Reclamation, HFC Replacement in Foam Production, HFC23 Destruction, N2O Destruction in Adipic Acid Production, N2O Destruction in Nitric Acid Production, Ozone Depleting Substances Recovery & Destruction, Propylene Oxide Production, Refrigerant Leak Detection, SF6 Replacement
Forestry & Land Use	Afforestation/Reforestation (impermanent), Avoided Forest Conversion, Avoided Grassland Conversion, Improved Forest

	Management, REDD++, Sustainable Grassland Management, Wetland Restoration
Household & Community	Biodigesters, Bundled Energy Efficiency, Clean Water, Community Boreholes, Cookstoves, Energy Efficiency, Lighting, Weatherization
Industrial & Commercial	Aluminium Smelters Emission Reductions, Brick Manufacturing Emission Reductions, Energy Efficiency, Fuel Switching, Grid Expansion & Mini-Grids, Carbon-Absorbing Concrete (Long-Duration), Leak Detection & Repair in Gas Systems, Mine Methane Capture, Natural Gas Electricity Generation, Oil Recycling, Pneumatic Retrofit, University Campus Emission Reductions, Waste Gas Recovery, Waste Heat Recovery
Renewable Energy	Biomass, Geothermal, Hydropower, RE Bundled, Solar – Centralized, Solar – Distributed, Solar Lightning, Solar Water Heaters, Wind
Transportation	Bicycles, Electric Vehicles & Charging, Fleet Efficiency, Fuel Transport, Mass Transit, Shipping, Truck Stop Electrification
Waste Management	Composting, Landfill Methane, Methane Recovery in Wastewater, Waste Diversion, Waste Incineration, Waste Recycling

A3. Variables selection and description

Table 6 The table gives a description of the variables selected and not selected for the thesis. The main variables are chosen from the Voluntary Registry Offsets Database, UNDP, and The World Bank. Descriptions retrieved from the database (Haya, Abayo, So, & Elias, 2022).

Variable	**Short Description**	**Relevance**	**Irrelevance**	**Brief Description/List of References to Previous Research**	**Where the Variable Was Used and How**
Project ID	The identification ID given by the registries.	Used to uniquely identify each project in the dataset.	-	-	Used in regressions as an ID key to merge and manage data.
Voluntary Registry	The project registry that issues and tracks offset credits.	-	Not directly relevant to the effectiveness analysis.	-	-
Voluntary Status	The status of the project on the voluntary market as designated by the registry.	-	Not directly relevant to the effectiveness analysis	-	-
Scope	Technological or environmental scope of the project.	Helps in understanding the project's environmental impact.	-	Scope often dictates project methodology and potential for carbon reduction (Fujii, et al., 2024).	Analysed in regression models to assess impact variations by project type.

Type	Each project is categorized by a type.	Specific project types may influence effectiveness.	Too many types, the sample size is too small for analysis.	-	Excluded from analysis due to diversity and sample size limitations.
Reduction / Removal	Categories of project impact: Reductions, Impermanent removals, Long-duration removals, or Mixed.	-	Almost all projects are reductions, not enough in the other categories to do analysis.	-	-
Region	Geographic region where the project is located.	Regional location may affect project success.	-	Regional effectiveness variations are significant (Castro & Michaelowa, 2008).	Used in regression analyses to compare effectiveness across different geographical areas.
Country	The country where the project takes place.	-	Breakdown of countries makes the sample size too small.	-	Excluded from analysis due to sample size limitations.
Total Credits Issued	The total number of credits issued by the registry from the start of the project.	Indicates project size and market engagement.	-	-	Used to make the effectiveness and to make the scale of projects and their relative impact in regression analyses.
Total Credits Retired	The total number of credits retired or cancelled from the start of the project.	Serves as a direct measure of project effectiveness.	-	-	Used to create the dependent variable in effectiveness analyses in regression models.
First Year of Project	The first year when credited reductions/removals occurred.	-	Insufficient data, do not have data for all projects.	-	-
Credits Issued by Vintage Year 1996-2022	Credits issued by year when reductions/removals occurred, often called the vintage year.	-	Text	-	-
Developing status	Status set by the UNDP for countries.	Influences available resources and technology for projects.	-	Developing status often correlates with different challenges and	Used to segment data and analyse differences in effectiveness

				opportunities in carbon offsetting (Fujii, et al., 2024; UNDP, 2003).	based on development status.
Carbon Mechanism	Overview of implemented mechanism by the World Bank.	Reflects the regulatory environment influencing project outcomes.	-	The presence of carbon mechanisms can enhance project accountability and effectiveness.	Analysed in regression to see if there's a statistical difference in project success with mechanisms.
Scale	Created variable based on size of the projects. Split dataset in half.	Scale may correlate with greater impact and visibility.	-	Scale affects project management complexity and potential success rates (Castro & Michaelowa, 2008; Fujii, et al., 2024).	Used to compare small vs. large project effectiveness in regression analysis.

B. Comparative analysis

B.1 Benchmarking effectiveness

Table 7 This table presents statistical summaries of the effectiveness of carbon offset projects, categorized by scale, region, scope, developing status, and carbon mechanism involvement. The effectiveness is measured from a scale of 0 (least effective) to 1 (most effective), with additional statistics provided for clarity.

Category							
Scale	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Large	0.567	0.000	0.205	0.640	0.943	1.601	2000
Small	0.596	0.000	0.027	0.778	1.000	1.079	2001
Region	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Carribean	0.360	0.000	0.004	0.384	0.620	0.904	11
Central America	0.420	0.000	0.000	0.383	0.899	1.079	53
Central Asia	0.569	0.000	0.325	0.504	0.913	1.000	7
East Asia	0.471	0.000	0.000	0.444	0.961	1.000	616
Europe	0.762	0.011	0.550	0.966	1.000	1.000	55
International	0.920	0.920	0.920	0.920	0.920	0.920	1
Middle East	0.498	0.000	0.132	0.513	0.865	1.000	216
North Africa	0.480	0.000	0.111	0.262	0.993	1.000	9
North America	0.644	0.000	0.262	0.829	1.000	1.059	1157
Oceania	0.678	0.000	0.334	0.969	0.995	1.017	14
South America	0.615	0.000	0.369	0.683	0.975	1.601	237
South Asia	0.572	0.000	0.129	0.669	0.995	1.000	794
South East Asia	0.540	0.000	0.035	0.599	0.949	1.048	173
Sub Saharan Africa	0.614	0.000	0.256	0.774	0.975	1.000	658
Scope	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Agriculture	0.713	0.000	0.499	0.954	1.000	1.012	258
Carbon Capture & Storage	0.624	0.386	0.505	0.696	0.699	0.833	5
Chemical Processes	0.607	0.000	0.017	0.912	1.000	1.000	346
Forestry & Land Use	0.527	0.000	0.069	0.601	0.899	1.601	536
Household & Community	0.534	0.000	0.006	0.631	0.954	1.000	899
Industrial & Commercial	0.594	0.000	0.039	0.771	1.000	1.000	210
Renewable Energy	0.583	0.000	0.215	0.648	0.992	1.048	1391

Transportation	0.707	0.000	0.588	0.838	0.964	1.000	46
Waste Management	0.642	0.000	0.412	0.758	0.995	1.000	310
Developing Status	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Developed	0.677	0.000	0.390	0.861	1.000	1.059	1122
Developing	0.545	0.000	0.080	0.608	0.969	1.601	2879
Carbon Mechanism	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
No	0.568	0.000	0.156	0.651	0.970	1.601	2038
Yes	0.596	0.000	0.107	0.743	1.000	1.059	1963

B.2 Effectiveness distribution across regions

Table 8 This table presents detailed statistical data on the effectiveness of various carbon offset project categories across different global regions. The effectiveness metrics are provided for each category, illustrating the diversity in project outcomes by geographical and sectoral distinctions.

Category							
Agriculture	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Central America	0.000	0.000	0.000	0.000	0.000	0.000	1
East Asia	0.073	0.000	0.000	0.000	0.059	0.565	32
Europe	0.391	0.044	0.289	0.425	0.543	0.623	6
Middle East	0.646	0.000	0.443	0.792	0.995	1.000	4
North America	0.816	0.000	0.713	0.994	1.000	1.000	185
South America	0.901	0.106	1.000	1.000	1.000	1.000	14
South Asia	0.842	0.000	0.948	1.000	1.000	1.000	9
South East Asia	0.833	0.000	0.989	1.000	1.000	1.012	6
Sub Saharan Africa	0.553	0.553	0.553	0.553	0.553	0.553	1
Carbon Capture and Storage	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
North America	0.624	0.386	0.505	0.696	0.699	0.833	5
Chemical Processes	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Carribean	0.127	0.127	0.127	0.127	0.127	0.127	1
East Asia	0.333	0.263	0.298	0.333	0.368	0.404	2
Europe	0.062	0.062	0.062	0.062	0.062	0.062	1
North America	0.604	0.000	0.011	0.907	1.000	1.000	332
South Asia	0.000	0.000	0.000	0.000	0.000	0.000	1
South East Asia	0.794	0.794	0.794	0.794	0.794	0.794	1
Sub Saharan Africa	0.992	0.933	1.000	1.000	1.000	1.000	8
Forestry and Land Use	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Caribbean	0.531	0.000	0.363	0.620	0.788	0.885	4
Central America	0.488	0.000	0.203	0.537	0.660	1.079	11
East Asia	0.325	0.000	0.055	0.271	0.457	1.000	41
Europe	0.155	0.155	0.155	0.155	0.155	0.155	1
North America	0.529	0.000	0.001	0.654	0.911	1.059	327
Oceania	0.893	0.271	0.984	0.995	1.000	1.017	7
South America	0.554	0.000	0.313	0.595	0.760	1.601	76
South Asia	0.478	0.013	0.254	0.476	0.758	0.833	7
South East Asia	0.557	0.010	0.260	0.649	0.792	1.000	12
Sub Saharan Africa	0.606	0.000	0.343	0.690	0.950	1.000	50
Household & Community	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Caribbean	0.398	0.384	0.391	0.398	0.405	0.413	2
Central America	0.369	0.000	0.000	0.016	0.839	1.000	22
East Asia	0.194	0.000	0.000	0.000	0.176	1.000	129
Europe	0.991	0.991	0.991	0.991	0.991	0.991	1
North Africa	0.862	0.731	0.797	0.862	0.928	0.993	2
North America	0.664	0.030	0.563	0.743	0.908	1.000	6
Oceania	0.522	0.522	0.522	0.522	0.522	0.522	1
South America	0.821	0.472	0.726	0.848	0.985	0.998	13
South Asia	0.490	0.000	0.000	0.449	0.976	1.000	154
South East Asia	0.748	0.000	0.628	0.895	0.966	1.000	30
Sub Saharan Africa	0.621	0.000	0.253	0.776	0.966	1.000	539

Industrial & Commercial	Mean	Min	Q1	Median	Q3	Max	Count
Caribbean	0.000	0.000	0.000	0.000	0.000	0.000	1
Central Asia	1.000	1.000	1.000	1.000	1.000	1.000	1
East Asia	0.543	0.000	0.000	0.634	0.983	1.000	41
Europe	0.882	0.110	0.880	0.993	1.000	1.000	40
Middle East	0.359	0.000	0.000	0.250	0.710	0.837	5
North America	0.514	0.000	0.000	0.459	1.000	1.000	71
South America	0.971	0.913	0.956	1.000	1.000	1.000	3
South Asia	0.488	0.000	0.004	0.519	0.943	1.000	39
South East Asia	0.527	0.000	0.031	0.608	0.996	1.000	5
Sub Saharan Africa	0.854	0.416	0.854	1.000	1.000	1.000	4
Renewable Energy	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Caribbean	0.304	0.000	0.004	0.009	0.456	0.904	3
Central America	0.512	0.000	0.000	0.634	0.992	1.000	17
Central Asia	0.497	0.000	0.309	0.430	0.746	1.000	6
East Asia	0.638	0.000	0.314	0.744	1.000	1.000	335
Europe	0.549	0.011	0.403	0.593	0.739	0.999	4
Middle East	0.507	0.000	0.149	0.549	0.867	1.000	195
North Africa	0.370	0.000	0.056	0.219	0.630	1.000	7
North America	0.820	0.000	0.844	0.905	1.000	1.000	21
Oceania	0.880	0.765	0.822	0.880	0.937	0.994	2
South America	0.604	0.000	0.329	0.722	0.960	1.000	111
South Asia	0.599	0.000	0.226	0.690	0.999	1.000	575
South East Asia	0.413	0.000	0.000	0.363	0.865	1.048	73
Sub Saharan Africa	0.490	0.000	0.015	0.505	0.964	1.000	42
Transportation	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
International	0.920	0.920	0.920	0.920	0.920	0.920	1
Middle East	0.000	0.000	0.000	0.000	0.000	0.000	1
North America	0.800	0.000	0.664	0.857	0.973	1.000	37
Oceania	0.000	0.000	0.000	0.000	0.000	0.000	1
South America	0.343	0.000	0.224	0.448	0.514	0.580	3
South Asia	0.333	0.000	0.000	0.000	0.500	1.000	3
Waste Management	**Mean**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Count**
Central America	0.024	0.000	0.012	0.024	0.036	0.048	2
East Asia	0.357	0.000	0.000	0.161	0.736	1.000	36
Europe	0.449	0.447	0.448	0.449	0.450	0.452	2
Middle East	0.387	0.024	0.081	0.356	0.555	0.998	11
North America	0.751	0.000	0.658	0.831	1.000	1.000	173
Oceania	0.321	0.000	0.000	0.000	0.481	0.962	3
South America	0.553	0.000	0.223	0.510	0.996	1.000	17
South Asia	0.615	0.054	0.445	0.597	0.937	1.000	6
South East Asia	0.559	0.000	0.045	0.695	0.968	1.000	46
Sub Saharan Africa	0.802	0.000	0.721	1.000	1.000	1.000	14

C. Regression robustness

Tables 9, 10 and 11 as well as Figures 11, 12, and 13 display the robustness checks for the Beta, Pooled OLS, and Tobit regression models. The Pooled OLS model better satisfies the normality assumptions required for classical regression analyses, as seen by a more uniform residuals distribution, while the Beta regression shows a bi-modal distribution suggestive of its bounded data character. High values of the Variance Inflation Factor (VIF) for the "Region" variable in both models indicate a substantial multicollinearity that may impair estimate precision. Additionally exhibiting a bi-modal distribution in residuals and comparable multicollinearity problems is the Tobit model. Although residual plots for all models typically show no systematic errors, indicating sufficient model fit without obvious heteroscedasticity or autocorrelation, QQ plots indicate small tail deviations that are especially relevant to the Tobit model. These diagnostics taken together emphasize the need of carefully interpreting regional effects and point to possible improvements in modelling techniques to better manage multicollinearity and improve the validity of the conclusions made regarding the efficacy of carbon offset projects.

C.1 Beta regression

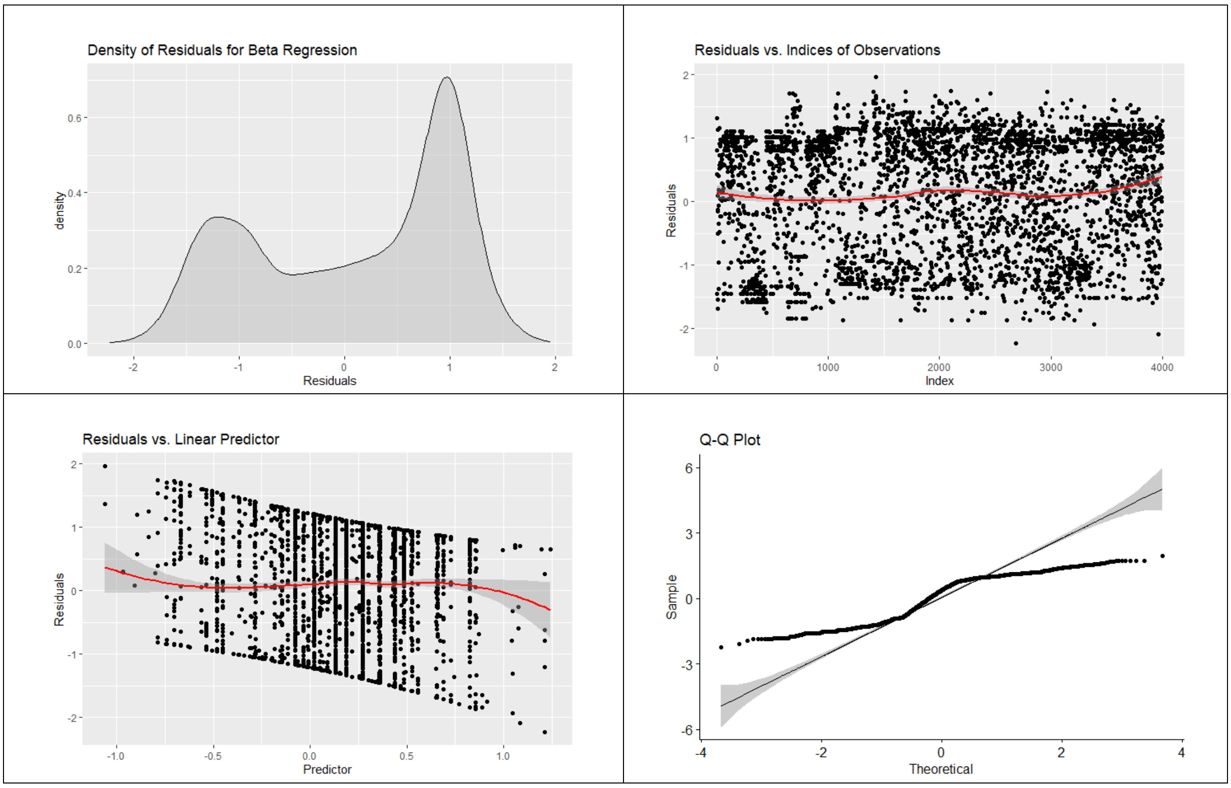


Figure 11 Robustness checks for Beta regression. Density of residuals, Residuals vs Indices of Observations, Residuals vs. Linear Predictor, and QQ-Plot.

Table 9 VIF for Beta regression. The high VIF for region stands out.

	GVIF	Df	GVIF^(1/(2*Df))
Scale	1.254	1	1.119
Region	84.130	13	1.185
Scope	7.193	8	1.131
Developing_Developed	7.953	1	2.820
Carbon_Mechanism	7.572	1	2.751

C2. OLS regression

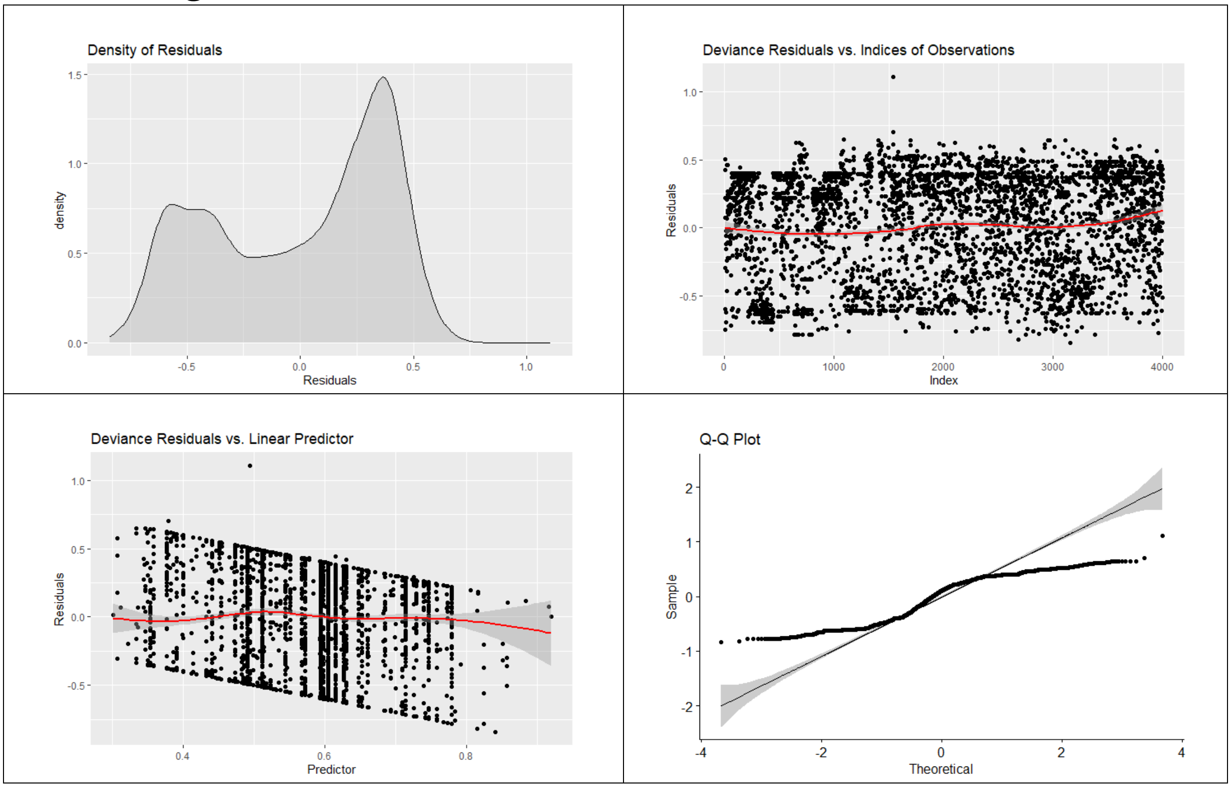
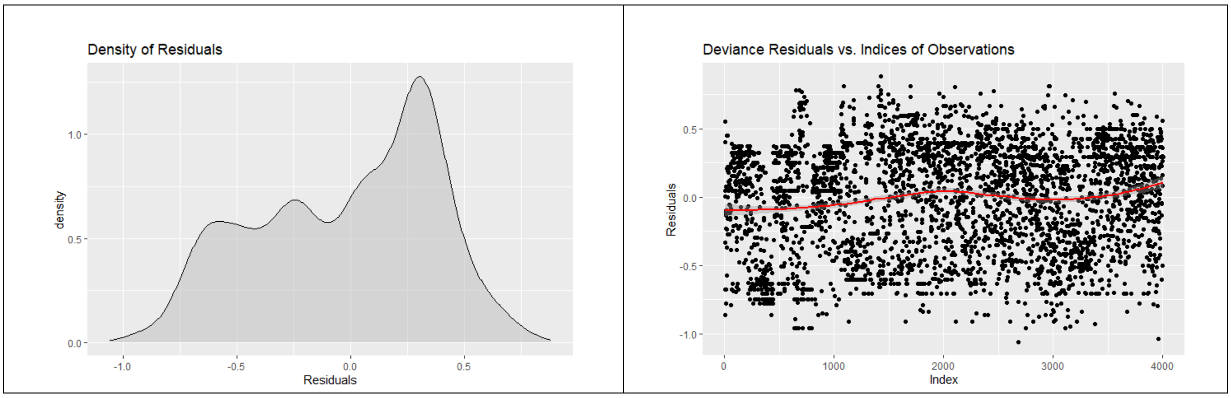


Figure 12 Robustness checks for Pooled-OLS regression. Density of residuals, Residuals vs Indices of Observations, Residuals vs. Linear Predictor, and QQ-Plot.

Table 10 VIF for Pooled OLS regression. The high VIF for region stands out.

	GVIF	Df	GVIF^(1/(2*Df))
Scale	1.258	1	1.121
Region	87.462	13	1.187
Scope	7.067	8	1.130
Developing_Developed	8.071	1	2.841
Carbon_Mechanism	7.647	1	2.765

C3. Tobit regression



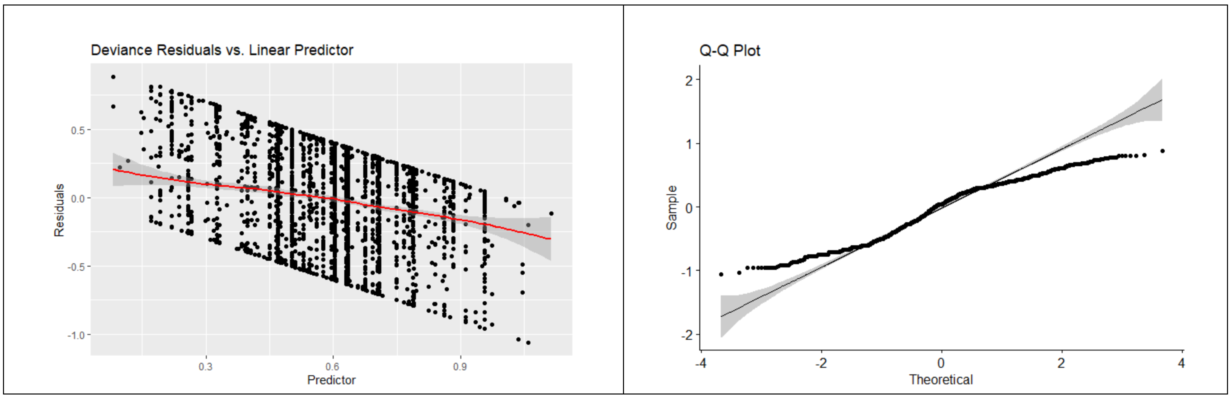


Figure 13 Robustness checks for Tobit regression. Density of residuals, Residuals vs Indices of Observations, Residuals vs. Linear Predictor, and QQ-Plot.

Table 11 VIF for Tobit regression. The high VIF for region stands out.

	GVIF	**Df**	**GVIF^(1/(2*Df))**
Scale	1.270	1	1.127
Region	89.758	13	1.188
Scope	7.167	8	1.130
Developing_Developed	8.245	1	2.871
Carbon_Mechanism	7.536	1	2.745