GREEN HARVEST: UNLOCKING THE POTENTIAL OF AGRICULTURAL LAND MANAGEMENT IN CARBON MARKET

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FOREWORD

The journey behind this report is as much personal as it is professional, a story of transformation driven by curiosity, passion, and an unrelenting desire to make a difference. My path into the intricate world of agricultural land management and carbon markets began during my years as a researcher at Embrapa, where I spent over a decade immersed in environmental research and innovation. But the turning point came when I was selected for the Nuffield Scholarship, a milestone that would not only expand my professional horizons but challenge me to rethink my role in addressing some of the most pressing environmental issues of our time.

For years, I had been working on climate change mitigation, but it was the Nuffield experience that inspired me to step outside the familiar corridors of public research and embrace the dynamic and rapidly evolving private sector. I realized that while my scientific foundation was strong, the scale and speed of the climate crisis demanded new approaches, and my role in it needed to evolve. Leaving Embrapa was not an easy decision; it was the culmination of deep reflection, catalyzed by the Nuffield journey, that pushed me to pursue solutions with greater urgency and impact.

My individual trips during the program were more than just professional visits; they were moments of profound discovery. I began in the Brazilian Cerrado, where the vast stretches of land and biodiversity reinforced my belief in the untapped potential of regenerative agriculture. This land, capable of producing abundant food and capturing carbon, holds immense promise for contributing to global decarbonization efforts. Standing on those soils, I felt a connection not only to the land but to the communities whose livelihoods depend on it. The Cerrado reminded me that solutions to climate change must integrate local knowledge and embrace sustainable practices that can benefit both people and the planet.

My journey then took me to the Paraguayan Chaco, a region of striking contrast—vast, remote, yet brimming with opportunity. Witnessing firsthand how sustainable farming practices can be adapted to this fragile ecosystem was eye-opening. The challenges were real, but so were the possibilities. It was here that I saw the power of innovation coupled with local engagement, understanding that the future of land management must consider not only environmental impact but also the livelihoods of the people who steward the land.

In California, I was introduced to the birthplace of the voluntary carbon market. Walking through the streets of San Francisco and Los Angeles, I experienced the innovative spirit that has driven carbon finance to new heights. The voluntary market there is a testament to the power of market-based solutions in addressing global issues. The people I met and the projects I visited shaped my understanding of how Latin America could adapt these models to its own reality, blending innovation with cultural and ecological context.

My journey culminated in New York City during Climate Week, where the convergence of global leaders, innovators, and activists from across the world left a lasting impression. Here, the urgency of action became even more apparent, and I was reminded that we are not alone in this fight. The global community is mobilizing, and I returned home more determined than ever to apply what I had learned to make meaningful contributions in my own region.

The Contemporary Scholars Conference (CSC) in the UK was a pivotal experience, where I explored sustainable farming practices, witnessed the integration of technology in agriculture, and gained insights into the potential of carbon markets. Visits to farms, agro-industries and the UK Parliament emphasized the critical role of governance and innovation in promoting sustainable management, while connections with global scholars enriched my perspective on addressing challenges collaboratively.

My journey as part of the Global Focus Program (GFP) was an incredibly enriching 1-month experience, traveling alongside 10 scholars from six different countries. Together, we explored diverse agricultural landscapes and systems in regions such as Rio Grande do Sul in Brazil, Texas in the USA, Germany, Northern Ireland, and Ireland. Each location offered unique insights into the challenges and innovations in farming, from the robust livestock systems in Texas to the advanced agricultural technologies in Germany. The diversity of perspectives and practices we encountered deepened my understanding of how agriculture can adapt to varying climates and cultures while remaining focused on sustainability and carbon mitigation. This cross-cultural exchange of ideas and experiences was invaluable in shaping my approach to global agricultural issues and solidifying the importance of collaboration in addressing shared climate challenges.

Through these experiences, I not only grew as a professional but as a person. Each country I visited, each conversation I had, brought new perspectives, pushing me to think more broadly about the challenges we face and the solutions we must pursue. This report is a reflection of that journey. It blends my scientific background with the real-world insights I gained from diverse landscapes, communities, and industries.

The journey is far from over. In fact, it is just beginning. Carbon markets and regenerative agriculture are still nascent fields, brimming with potential to shape the future of sustainable farming and climate solutions. With the knowledge and experiences gained through Nuffield, I am more determined than ever to continue learning, sharing, and applying these insights to help build a more sustainable and equitable future for agriculture - and for the planet.

Table 1. Travel itinerary

Travel date	Location	Visits/contacts
CSC	United Kingdon	An extremely full agenda
Week 1	Mato Grosso do Sul, Brasil	Farms with regenerative agriculture and degraded pastures
Week 2	Assunción and Chaco, Paraguay	Farms, slaughterhouse and cooperatives
Week 3	San Francisco, USA	Farms and carbon credit companies
Week 4	Los Angeles, USA	Farms and carbon credit companies
Week 5	New York, USA	Climate Week 2023
GFP	Rio Grande do Sul, Brazil; Texas, USA; Germany; North Ireland and Ireland.	Farms, companies, government agencies and industries

ACKNOWLEDGMENTS

No journey is ever taken alone, and this one has been filled with remarkable people who have guided, supported, and walked alongside me, helping me grow and discover new horizons. As John Donne once wrote, "No man is an island, entire of itself; every man is a piece of the continent, a part of the main." This journey has been, above all, a shared experience, woven together by the love, friendship, and support of many.

To Marcela, the love of my life and my constant compass. Thank you for being that unwavering force, always supporting me through my “crazy” ideas, endless travels, studies, and times of absence. You are the best mother our daughters could ever dream of, and you are, without question, our safe harbor. Your love, patience, and strength inspire me to be the best version of myself every single day.

To Luiza and Alice, my beloved daughters, you are the heart of everything I do. You give me the motivation to strive for greatness, and your presence fills my life with joy and purpose. Thank you for being the incredible daughters you are, and for making my world a better place every day. You are the light that guides me forward, and I hope one day you will be proud of the path I’ve taken.

To my parents, who taught me the meaning of love, friendship, and lifelong learning. You have always believed in me, encouraged me to pursue knowledge, and given me the best education anyone could ask for. You are my eternal examples of dedication and curiosity. Lifelong learning has been our foundation, and for that, I will always be grateful.

To Sally Thomson, who introduced me to Nuffield and has led us with grace and wisdom. Your leadership, constant encouragement, and unwavering friendship have inspired me in ways words cannot express. You’ve ignited a fire in me for seeking knowledge, resolving conflicts, and always striving for more. Thank you for believing in me and for creating such a wonderful space for all of the scholars.

My deep gratitude goes to TIAA for sponsoring this scholarship and giving me the opportunity to be part of the Nuffield journey, which has undoubtedly been the most intense, challenging, and rewarding experience of my professional life. And I say “journey” in the present tense because this doesn’t end with the completion of this report. Nuffield is a lifelong adventure. I offer special thanks to Martin Davies, Henrique Americano, and André Chaves, whose support, encouragement, and leadership have been invaluable. You are professionals I deeply admire, and I aspire to follow in your footsteps.

Finally, to my fellow Nuffield scholars, thank you for making this network such an incredible place to grow, learn, and share. The friendships forged during the CSC and GFP have been some of the greatest gifts of this journey. To those friends who accompanied me on this path, thank you for your companionship, laughter, and shared moments of wonder and discovery.

This journey is not mine alone. It belongs to all of you, and for that, I am forever grateful. “We make a living by what we get, but we make a life by what we give.” - Winston Churchill.

Thank you all for giving so much!

Abbreviations

ABC: Low Carbon Agriculture Plan

APP: Areas of Permanent Preservation

BAU: Business-as-Usual

CDM: Clean Development Mechanism

CO_2: Carbon Dioxide

COP: Conference of the Parties

CSC: Contemporary Scholars Conference

GFP: Global Focus Program

GHG: Greenhouse Gas

ICL: Integrated Crop-Livestock

ICLF: Integrated Crop-Livestock-Forestry

IPCC: Intergovernmental Panel on Climate Change

NBS: Nature-based Solutions

NDC: Nationally Determined Contribution

PES: Payment for Environmental Services

RL: Legal Reserve

TIAA: Teachers Insurance and Annuity Association

UNFCCC: United Nations Framework Convention on Climate Change

EXECUTIVE SUMMARY

This report explores how agricultural land management can be integrated into carbon market systems, with a particular focus on Brazil's Cerrado biome. The research examines regenerative agricultural practices, such as integrating crops and livestock, and restoring degraded pastures, to assess their potential to reduce greenhouse gas emissions, sequester carbon, and improve farmers' incomes.

While I came into this project with significant experience in environmental science and agricultural systems, the Nuffield journey profoundly expanded my perspective. By visiting countries with diverse approaches to sustainability, I gained a broader understanding of global agricultural practices. This experience highlighted not only the innovative methods being used abroad but also the considerable sustainability achievements already present in Brazilian agriculture. It became clear to me that Brazil’s agribusiness is often underappreciated for its sustainable efforts, and we must improve how we communicate these successes to the world.

The Nuffield journey also solidified my belief that carbon markets present an excellent opportunity to showcase and certify these sustainable practices in a transparent and robust way. By integrating Brazil’s existing efforts into a formal carbon credit system, we can unlock new financial benefits while contributing to global climate change mitigation.

The study included in this report has three main objectives. First, it assesses the potential for sustainable farming practices to capture carbon and reduce emissions. Second, it evaluates the economic viability of these practices, including their potential to generate revenue through carbon credits. Finally, it highlights the broader environmental and social benefits that can arise from adopting regenerative agricultural systems, such as better soil health, enhanced biodiversity, and improved rural livelihoods.

A case study of a hypothetical farm in the Brazilian Cerrado, covering 1,000 hectares with 35% preserved under the Brazilian Forest Code, illustrates different land management scenarios. These range from current practices that continue to degrade land, to advanced systems like Integrated Crop-Livestock (ICL) and Integrated Crop-Livestock-Forestry (ICLF). The results show that regenerative methods can sequester more than 100,000 tons of CO_2 equivalent over ten years, while also reducing methane and nitrous oxide emissions.

The economic analysis reveals that integrating crops, livestock, and forestry boosts farm productivity and profitability. Farmers can diversify their income and potentially generate revenue through carbon credits, offering a new pathway for sustainable growth. Scaling up these practices could position Brazil as a global leader in low-carbon agriculture, particularly given the vast areas of degraded pastureland in the country. This would not only benefit the environment but also create jobs and strengthen rural economies.

In conclusion, the report underscores the enormous potential of sustainable agricultural practices to drive both environmental and economic progress. By improving farm productivity and resilience while reducing emissions, these practices support global climate goals. The recommendations call for policies that improve farmers' access to carbon markets, offer financial and technical support, and strengthen the frameworks that incentivize sustainable practices. By fostering public-

private partnerships and continuing to innovate in sustainable agriculture, Brazil can set an example for integrating agriculture and carbon markets on a global scale.

And while this report marks the formal conclusion of my Nuffield program, the learning journey continues. Nuffield embodies the principle of Lifelong Learning, and the experiences, insights, and connections gained throughout this process will continue to shape my professional and personal growth. The lessons learned will remain a part of me as I apply this knowledge in my ongoing efforts to promote sustainable agriculture and carbon market integration.

Keywords: Regenerative Agriculture; Carbon Sequestration; Carbon Markets; Sustainable Land Management; Climate Change Mitigation; Sustainability.

OBJECTIVES

The objectives of this report are structured to explore the intersection of agricultural land management and the carbon market, focusing on the potential of regenerative agricultural practices in Brazil’s Cerrado biome. These objectives guide the content and structure of the report, ensuring a clear and focused analysis throughout. The primary objectives are:

Objective 1: Provide a comprehensive explanation of climate change and its global impacts.

Offer an in-depth exploration of the scientific basis of climate change, its physical drivers, and its socio-environmental consequences, ensuring the reader fully understands the urgency and complexity of this global issue.

Objective 2: Analyze the international climate negotiations and the role of carbon markets:

Present a detailed examination of international climate negotiations (e.g., COP meetings, the Paris Agreement) and the evolution of carbon markets, emphasizing their relevance in addressing climate change and fostering global cooperation on emissions reduction.

Objective 3: Assess the carbon sequestration and potential and the reduction of greenhouse gas emissions of regenerative agricultural practices

Evaluate how integrated crop-livestock and agroforestry systems can enhance carbon sequestration in degraded pasturelands, contributing to global climate change mitigation efforts. Quantify the reduction of methane and nitrous oxide emissions from regenerative agricultural practices compared to conventional systems, highlighting their environmental benefits.

Objective 4: Identify the environmental, economic, and social co-benefits of regenerative agriculture

Explore the broader benefits of regenerative farming, including improvements in soil health, biodiversity, rural development, and resilience to climate change, and propose pathways for scaling these practices across Brazil.

1 INTRODUCTION

The world is currently facing a critical environmental challenge - climate change, driven by the increasing concentration of greenhouse gases (GHGs) in the atmosphere. As global efforts intensify to mitigate these effects, agriculture, one of the largest sectors in terms of land use and emissions, is emerging as both a contributor and a potential solution. The primary purpose of this research is to explore how sustainable agricultural land management can play a transformative role in the carbon market, offering opportunities for climate change mitigation while simultaneously creating economic value for farmers. By focusing on practices that enhance carbon sequestration and reduce emissions, this study aims to demonstrate how agriculture can transition from being a significant source of GHGs to becoming a key driver in the global effort to decarbonize the economy.

The scope of this research is broad, encompassing several critical areas at the intersection of agriculture and carbon markets. First, it examines the concept of carbon markets, including both regulated and voluntary systems, and how they can incentivize farmers to adopt sustainable practices. These markets offer financial mechanisms, such as carbon credits, that reward landowners and agricultural businesses for reducing or sequestering carbon emissions. Understanding how these markets function, their economic models, and their potential for growth is crucial for unlocking the full potential of agricultural land in mitigating climate change.

Another important area covered by the research is the exploration of key land management practices that can contribute to carbon sequestration. These include regenerative agriculture, agroforestry, no-till farming, and the restoration of degraded lands. These practices not only improve soil health and boost agricultural productivity but also capture carbon dioxide (CO_2) from the atmosphere, storing it in the soil and biomass. By focusing on these sustainable practices, the research highlights the dual benefits of improving ecosystem resilience while providing farmers with new revenue streams through participation in carbon markets.

This research also addresses the policy frameworks and financial instruments that can drive the adoption of carbon-friendly agricultural practices. In particular, it examines the role of environmental services payments (PES) as an incentive for farmers to engage in sustainable land management. By paying farmers for the environmental benefits their practices generate, PES schemes can help align economic incentives with environmental goals. The research explores how these mechanisms can be integrated into existing agricultural systems, particularly in tropical regions like the Brazilian Cerrado, which is a key focus area due to its vast agricultural potential and high carbon sequestration capacity.

The geographical focus of this study is centered on the Brazilian Cerrado, one of the most biodiverse and agriculturally significant regions in the world. As a vast savanna with immense potential for both food production and carbon storage, the Cerrado plays a crucial role in global sustainability efforts. Large areas of degraded pastureland across this biome offer significant opportunities for restoration, which could lead to substantial carbon sequestration. This makes the Cerrado an ideal case study to examine how sustainable agricultural practices - such as regenerative farming and integrated crop-livestock-forest systems - can generate both climate benefits and economic returns through participation in the carbon market. Although this research is focused on the Cerrado, the findings and methodologies could be applied to similar tropical regions across the planet, such as the rainforests of Southeast Asia and the savannas of Sub-Saharan Africa, where sustainable land management practices have the potential to make a similar impact on carbon sequestration and rural development.

In addition to exploring the technical and economic aspects of carbon markets, the research seeks to provide a comprehensive overview of the barriers and drivers to the adoption of sustainable practices in agriculture. These include market access, regulatory challenges, knowledge gaps, and financial risks for farmers. By identifying and addressing these challenges, the study aims to offer actionable recommendations for policymakers, private sector stakeholders, and farmers on how to scale sustainable land management practices and maximize their contribution to carbon markets.

In summary, this research provides an in-depth analysis of the potential for agricultural land management to contribute to climate change mitigation through the carbon market. It highlights the economic opportunities available to farmers through carbon credits and environmental services payments, while also emphasizing the importance of sustainable land practices that enhance ecosystem resilience. By focusing on both the technical and policy aspects, the study offers a roadmap for integrating agriculture into global climate strategies, ensuring that the sector can play a leading role in the transition to a low-carbon economy.

1.2 Background and Context

1.1.1 The Physical Basis of Climate Change: What is Natural and What is Human-Induced?

Climate change is an increasingly relevant topic both within the scientific community and to society. Understanding the physical bases that govern these changes is essential for addressing current and future environmental challenges. Climate alterations directly impact our daily lives, from extreme weather events to the availability of natural resources. The discussion about climate is not just about future predictions; it is about understanding processes that are already underway and profoundly affecting the balance of our planet.

To deepen this understanding, it is crucial to differentiate between two often-confused concepts: weather and climate. While weather refers to short-term atmospheric conditions in a specific area, such as temperature, precipitation, and humidity, climate encompasses long-term weather patterns that define a region's characteristics over decades or even centuries. This distinction is crucial to understanding how climate changes can be more subtle and gradual but with profound and lasting impacts.

In this section, we will explore a central question: how to distinguish the natural effects of climate change from those caused by human activities? We will address the physical basis of climate change by analyzing both natural and anthropogenic factors and discussing the implications of these changes for the future of our planet.

1.1.2 Defining Climate Change

Climate change refers to significant and long-term changes in the Earth's climate patterns. Naturally, the climate of our planet has always varied due to factors such as solar radiation, volcanic activity, and oceanic cycles like El Niño and La Niña. These variations are normal and part of the Earth's natural cycles. According to IPCC (2007), climate change is identified by the average and/or variability of its properties (temperature, rainfall, etc.) over a period of time or even decades. This variability can be caused by natural or anthropogenic causes.

However, since the Industrial Revolution, human activity has introduced new elements that drastically alter these natural patterns. The massive emission of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) resulting from the burning of fossil fuels, deforestation, and industrial and agricultural activities is warming the atmosphere at an unprecedented rate. It is essential to understand these differences so that we can identify the root of current climate problems.

Moreover, climate change is not limited to the increase in global temperatures but also encompasses a range of environmental impacts such as rising sea levels, changes in precipitation patterns, ocean acidification, and the intensification of extreme weather events (IPCC, 2007; IPCC, 2013; IPCC, 2022). These changes are occurring rapidly and with an intensity that challenges the ability of ecosystems and human societies to adapt. It is the interaction between natural factors and anthropogenic pressures that shapes the complex climate reality we face today. Understanding this dynamic is crucial for formulating effective mitigation and adaptation strategies that can reduce negative impacts and promote a more sustainable and resilient future for all.

1.1.3 Natural Effects vs. Human Activities

The natural effects on Earth's climate are determined by a series of factors that operate on different time and space scales. These factors include solar variability, Milankovitch cycles, and geophysical events such as major volcanic eruptions. Each of these processes plays a crucial role in modulating the global climate and can cause significant changes in atmospheric conditions.

Solar Variability:

Solar variability refers to changes in the amount of solar radiation the Earth receives. These variations can occur in cycles of approximately 11 years, known as solar cycles, marked by fluctuations in sunspot activity. During periods of high solar activity, the Earth receives more radiation, which can lead to temporary warming. Conversely, during periods of low solar activity, such as the Maunder Minimum in the 17th century, the Earth can experience cooler conditions (Haigh, J. D., 2003). These solar cycles directly influence the amount of energy reaching the Earth, affecting short-term climate patterns.

Greenhouse effect:

The greenhouse effect is a natural process that keeps the Earth's climate stable and warm enough to support life. It functions by allowing the Earth to absorb solar energy while retaining enough heat to maintain a habitable temperature. However, this delicate balance is being disrupted by human activities, amplifying the greenhouse effect and driving global warming, as shown in figure 1.

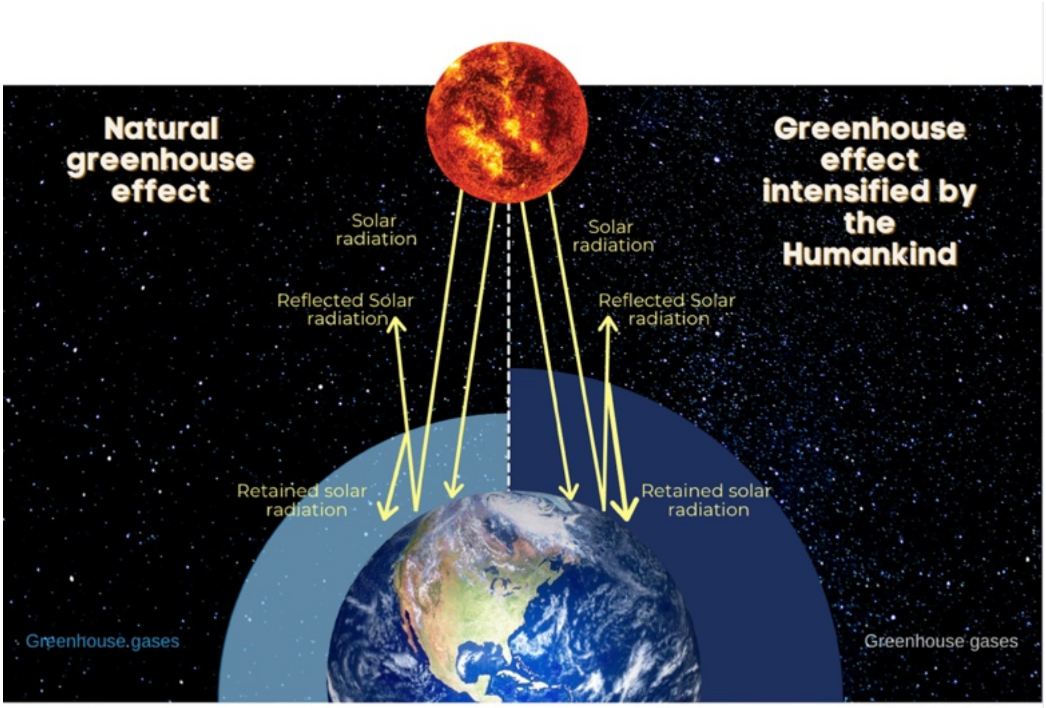

Figure 1: Representation of the natural greenhouse effect and the greenhouse effect intensified by the Humankind. Elaborated by the author.

Natural Greenhouse Effect:

Under normal circumstances, the greenhouse effect works as follows: solar radiation enters the Earth's atmosphere, where some of it is absorbed by the Earth's surface and some is reflected back into space. The absorbed solar energy heats the Earth, which in turn radiates heat (infrared radiation) back towards space. However, greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and water vapor trap some of this outgoing infrared radiation, preventing it from escaping the atmosphere and re-radiating it back to the Earth's surface. This natural trapping of heat by greenhouse gases keeps the Earth's average temperature around 15°C, which is vital for maintaining the ecosystems and climate conditions that support life.

As shown in the figure 1, the natural greenhouse effect allows the Earth to retain solar radiation (illustrated by the yellow arrows) while some of the energy is reflected back into space. The balanced process of absorption and reflection ensures the Earth remains warm, yet not overheated.

Human-Enhanced Greenhouse Effect:

However, human activities, particularly the burning of fossil fuels and deforestation, have dramatically increased the concentration of greenhouse gases in the atmosphere. This intensified greenhouse effect means that more heat is trapped, leading to an unnatural warming of the Earth, known as global warming. The figure illustrates how, with increased greenhouse gases due to human activities, more solar radiation is retained within the atmosphere, preventing heat from escaping into space.

Since the Industrial Revolution, atmospheric CO_2 levels have risen sharply due to emissions from industry, transportation, and energy production. The excess greenhouse gases amplify the natural greenhouse effect, retaining more heat than the Earth would otherwise. This results in higher global temperatures, altered weather patterns, and increased frequency of extreme weather events.

<u>The Consequences of an Intensified Greenhouse Effect:</u>

- The enhanced greenhouse effect contributes to rising global temperatures, which in turn leads to significant climate disruptions. Some of the consequences include:
- Global Warming: A steady rise in global temperatures, leading to melting ice caps, rising sea levels, and shifting climate zones.
- Extreme Weather Events: An increase in the frequency and intensity of extreme weather events such as hurricanes, floods, and droughts.
- Disruption of Natural Ecosystems: Warming temperatures can alter habitats and endanger species that cannot adapt quickly enough, resulting in biodiversity loss.
- Impact on Agriculture: Changing weather patterns can reduce crop yields and disrupt food security, particularly in vulnerable regions.
- Ocean Acidification: Increased CO_2 absorption by the oceans is causing acidification, threatening marine ecosystems, particularly coral reefs.

Figure 1 visually represents the difference between the natural greenhouse effect and the human-enhanced effect. On the left, we see the natural balance where some solar radiation is reflected, and some is retained by greenhouse gases. On the right, the intensified effect shows how human activity has thickened the layer of greenhouse gases, leading to more retained heat and increased global temperatures.

In summary, while the greenhouse effect is necessary for life on Earth, human activities are amplifying this effect to dangerous levels. The intensification of the greenhouse effect due to increased GHGs is the primary driver of current global climate change, requiring immediate action to mitigate its impacts.

Milankovitch Cycles:

Milankovitch cycles describe variations in the Earth's orbit and the tilt of its axis, occurring over tens to hundreds of thousands of years (figure 2). These cycles are divided into three main components (Broecker et al., 1968; Berger, 2002):

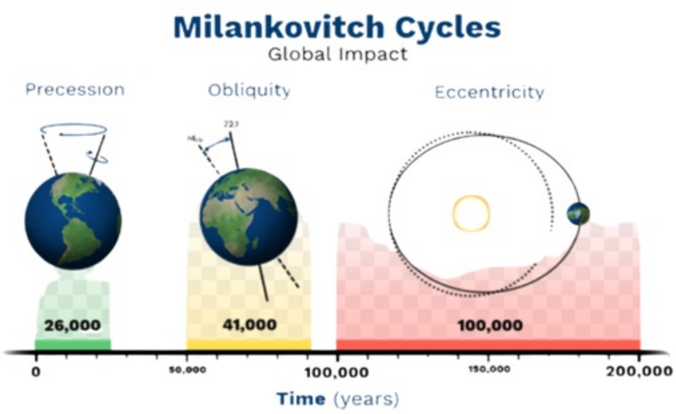

Figure 2: Milankovitch cycles.

- Eccentricity: Variation in the shape of the Earth's orbit, oscillating between more circular and more elliptical every approximately 100,000 years. A more elliptical orbit can mean greater seasonal differences in the amount of solar radiation received.

- Obliquity: Change in the angle of the Earth's axial tilt, varying between 22.1° and 24.5° in a cycle of about 41,000 years. Greater tilt increases the intensity of the seasons, with hotter summers and colder winters.
- Precession: Change in the orientation of the Earth's axis in a cycle of approximately 26,000 years. Precession affects the timing of when the Earth is closest or farthest from the Sun, influencing the seasonal distribution of solar radiation.

Milankovitch cycles are widely accepted as the main mechanisms driving the Earth's glacial and interglacial cycles, causing periods of warming and cooling that can last tens of thousands of years.

Volcanic Eruptions:

Major volcanic eruptions can have a significant and immediate impact on the global climate by releasing large amounts of particles and gases such as sulfur dioxide (SO_2) into the stratosphere. These particles reflect sunlight back into space, reducing the amount of radiation reaching the Earth's surface and causing a temporary cooling effect (USGS, 2024) . A notable example is the eruption of Mount Tambora in 1815, which resulted in the "Year Without a Summer" of 1816, causing abnormally low temperatures and crop failures in various parts of the world.

These natural factors interact in complex and often unpredictable ways, influencing the Earth's climate over different time periods. However, it is important to highlight that while these natural processes continue to operate, the climate changes observed in recent decades are primarily attributed to human activities, as we will discuss in the next section.

Human Activities:

Human activities have significantly accelerated the climate change process. The burning of fossil fuels such as coal, oil, and natural gas releases enormous amounts of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere, amplifying the Earth's natural greenhouse effect and resulting in global warming. These emissions are responsible for about 78% of the increase in the greenhouse effect since 1970 (IPCC, 2007). Moreover, deforestation and forest degradation, which act as important carbon sinks, reduce the planet's capacity to absorb CO_2, exacerbating the problem further.

The historical contribution to greenhouse gas emissions is not uniform among countries. Historically, industrialized countries such as the United States, the European Union, and Japan are the largest contributors to cumulative CO_2 emissions since the beginning of the Industrial Revolution (ClimateWatch, 2024). In fact, the United States alone is responsible for about 25% of cumulative global emissions since 1750, followed by the European Union with about 22% (ClimateWatch, 2024) . This is largely due to the extensive use of fossil fuels for industrialization and economic development over the 19th and 20th centuries.

Developing countries, although currently increasing their emissions due to rapid economic growth and rising energy demand, have significantly lower historical responsibilities. For example, China, which is currently the world's largest annual CO_2 emitter, has contributed only about 13% of cumulative global emissions to date. In contrast, African countries, despite being the least responsible for historical greenhouse gas emissions, are among the most vulnerable regions to the impacts of climate change.

The unequal distribution of emissions not only reflects the different development trajectories of countries but also highlights the need for climate justice in global policies. Countries that have historically emitted the most greenhouse gases have the greatest responsibility to lead efforts to reduce emissions and support the most vulnerable nations in adapting to climate change.

Deforestation, particularly in tropical regions such as the Amazon, has also significantly contributed to greenhouse gas emissions. Tropical forests act as major carbon sinks, absorbing CO_2 from the atmosphere and storing it in biomass. The destruction of these forests not only releases large amounts of stored CO_2 but also diminishes the Earth's capacity to absorb future emissions, aggravating the global warming problem.

The combination of these human activities with industrial emissions results in a climate change of unprecedented pace and magnitude, challenging the adaptation capacity of natural ecosystems and human societies. Understanding the historical and contemporary contribution of greenhouse gas emissions is crucial for formulating effective mitigation policies and promoting a just and sustainable transition to a low-carbon economy. Reports presented by the Intergovernmental Panel on Climate Change demonstrate that the phenomenon of global warming could raise the planet's temperature by 2.6°C to 4.8°C by the end of the 21st century, generating negative regional and global impacts (IPCC, 2013) .

Comparing the Past and the Present:

The analysis of paleoclimatic data reveals that the Earth's climate has always been subject to significant changes over millions of years, driven by natural factors such as variations in the Earth's orbit, changes in solar activity, and geological events (Indermuhle et al., 2000a; Indermuhle et al., 2000b; Petit et al., 1999). These data, obtained from ice cores, ocean and lake sediments, and tree rings, show that the Earth has gone through cycles of warming and cooling, such as ice ages and interglacial periods.

However, the climate change observed today is markedly different in terms of speed and intensity. The rate of warming seen in recent decades is unprecedented in paleoclimatic records. Since the Industrial Revolution, approximately 150 years ago, the global average temperature has increased by about 1.1°C, a rate of change much faster than any previous natural event. For comparison, transitions between glacial and interglacial periods, which involved similar temperature changes, occurred over thousands of years (Indermuhle et al., 2000a; Indermuhle et al., 2000b; Petit et al., 1999).

The ice ages, for example, were characterized by long periods of extremely low temperatures, followed by gradual warming periods that led to the retreat of ice sheets and sea level rise. These transitions took thousands of years and were driven by slow and predictable variations in the Earth's orbit and axial tilt. In contrast, the current warming is driven by a rapid accumulation of greenhouse gases in the atmosphere, mainly from the burning of fossil fuels and deforestation, occurring on a timescale of just a few decades.

Extreme weather events such as floods, droughts, heatwaves, and storms are becoming increasingly frequent and severe. A report from Cred & UNDRR (2021) comparing the number of disasters in 2020 with the average data from 2000 to 2019 shows an increase in natural disasters worldwide. The devastating floods in Rio Grande do Sul in March/April 2024, for example, are indicative of increased rainfall intensity exacerbated by rising global temperatures, which intensify the hydrological cycle. Studies show that extreme precipitation events have increased in frequency and intensity in recent decades due to global warming.

Climate model analyses suggest that global warming will intensify the Earth's hydrological cycle and increase the risk of floods and droughts (Asadieh and Krahauer, 2017) . Approximately 10% of the world's land area is projected to simultaneously experience an increase in high extreme streamflow and a decrease in low extreme streamflow, reflecting a potential increase in the risk of both flooding and drought (Asadieh and Krakauer, 2017) .

Natural climate variability, including phenomena such as El Niño and La Niña, can also trigger extreme weather events, but the current frequency and intensity of these events are far beyond what would be expected based solely on natural variability. Climate models and historical data indicate that natural climate variability cannot explain the rapid climate change and extremes we are witnessing today. For example, temperature measurements and data on extreme events show that since the early 20th century, the occurrence of extreme heat events has significantly increased, while the frequency of extreme cold events has decreased a pattern consistent with human-induced global warming.

Implications and Future Consequences:

Climate change is already having profound impacts worldwide. Rising sea levels, the loss of polar ice, and the intensification of extreme weather events are becoming more evident (IPCC, 2022) . Climate models indicate that if we do not drastically reduce greenhouse gas emissions, global temperatures will continue to rise, resulting in devastating consequences for the environment and society (IPCC, 2022).

Among the most concerning impacts are water scarcity, decreased agricultural productivity, loss of biodiversity, and the increased frequency of natural disasters such as storms and droughts. These changes will affect all regions of the planet but will be particularly severe in vulnerable areas, such as northeastern Brazil, which already faces significant challenges related to water scarcity and desertification (IPCC, 2022).

Key Takeaways:

Understanding the physical basis of climate change is fundamental to distinguishing between natural effects and those caused by human activity. Science provides irrefutable evidence: human activity is the primary driver of the climate change we observe today, and its consequences are becoming increasingly evident and devastating. Immediate and effective measures must be taken to mitigate these impacts and adapt to the changes already underway (IPCC, 2013; IPCC, 2022).

Each of us has a crucial role in the fight against climate change. We need to adopt more sustainable practices in our daily lives, from reducing energy consumption to supporting public policies that promote sustainable development. Governments, businesses, and individuals must work together to reduce greenhouse gas emissions and invest in clean and renewable technologies.

Brazil, with its vast natural wealth and biodiversity, has a unique responsibility and opportunity. As one of the largest emerging economies and home to the world's largest tropical rainforest, Brazil can lead by example by promoting sustainable agricultural practices, protecting its forests, and investing in clean energy. The preservation of the Amazon and other critical ecosystems is vital not only for combating climate change but also for maintaining biodiversity and ecosystem services that sustain life on our planet.

As we explore the dynamics of climate change, it becomes evident that this challenge also brings opportunities for innovation and progress. Throughout this report, we will examine tools and strategies that can contribute to a more sustainable and resilient future. By adopting regenerative agricultural practices and leveraging the carbon market, we can make significant strides toward a healthier and more balanced planet for future generations.

2 INTERNATIONAL NEGOTIATION ON CLIMATE CHANGE

2.1 The UNFCCC

The International Negotiations on Climate Change take place within the framework of the United Nations Framework Convention on Climate Change (hereinafter referred to as Convention), having as its main stage the Conference of the Parties (COP) which happens annually, with the presence of all signatory countries to the Convention. However, for achieving the status of the largest multilateral agreement in history, it took a long road for creation and subsequent consolidation of the Convention.

In 1988, the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC), with the aim of scientifically evaluating knowledge climate change, assess possible socioeconomic and environmental impacts, and formulate realistic strategies to deal with the problem. This was one of the most important in recognizing the effect of greenhouse gases on the climate system. The IPCC had the participation of important scientists and experts on related subjects to the problem of climate change. The first IPCC assessment report was published in 1990 and led the UN General Assembly to create the Convention.

To create the Convention, it was necessary to go through an intense preparatory political process, as there was a need to develop international policies and instruments legal issues related to climate change (Mendes, 2014). This process culminated in the realization of the United Nations Conference on Environment and Development, in Rio de Janeiro, in 1992. The Convention came into force in 1994 and Brazil was the first country to ratify the agreement.

Even for the time, and considering the lack of full knowledge regarding the processes and impacts of climate change, the text of the Convention brought great advances for discussion about the environment. The Convention recognizes, among other than (UNFCCC, 1992):

➔ Earth's climate change and its negative effects are a common concern of humanity;

➔ the largest portion of global, historical and current, greenhouse gas emissions originate from developed countries;

➔ per capita emissions from developing countries are still relatively low and the share of global emissions originating from developing countries will grow so that they can meet their social and development needs.

The ultimate objective of the Convention is (UNFCCC, 1992):

> "Achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system."

The text also warns that such a level must be reached within a period of time

enough to allow ecosystems to adapt naturally to climate change; ensure that food production is not threatened; and enable the development economic progress continues in a sustainable manner.

The Convention follows the principle of Multilateralism, present in the charter of creation of the UN, which considers each signatory country to be a Party to the agreement (hence the term "Conference of the Parties) and even though to make any decision it is necessary to reach the consensus and no, a simple majority of votes. And yet, those simple decisions are part of a global agreement that interests all Parties. In the language of negotiation: "nothing is decided until everything is decided".

To achieve its final objective, the Convention imposed on a group of countries,

reduction of greenhouse gas emissions. These countries were listed in Annex I of the Convention and represent the developed countries (and which represent the majority of emissions, the concentration of gases in the atmosphere and the increase in the planet's average temperature). The Convention did not impose initial emission reduction targets for countries in development and least developed countries.

The Convention also brings two extremely important principles for the consolidation of international negotiation and sustainable development, especially in developing countries development (UNFCCC, 1992).

> Precautionary Principle: the lack of full scientific certainty should not be used as a reason for countries to postpone the adoption of measures to predict, avoid or minimize the causes of climate change and mitigate its negative effects.
>
> Principle of Common but Differentiated Responsibilities: Parties shall protect the climate system for the benefit of present and future generations of humanity, on the basis of equity and in accordance with their respective common but differentiated responsibilities
>
> capabilities.

In this sense, the Parties, developed countries, must take the lead in combating climate change and the adverse impacts of this change.

The Convention, through the Principle of Common but Differentiated Responsibilities, proposed a series of commitments common to all signatory Parties, such as (UNFCCC, 1992):

- Prepare the National Communication, containing the Inventory of anthropogenic greenhouse gas emissions by gas and sector of the economy;
- Promote mitigation and adaptation programs;
- Develop technologies to reduce and prevent emissions;
- Protection of carbon sinks, such as forests and oceans;
- Consider climate change in social, economic and environmental policies;
- Promote scientific research on climate change;
- Promote education, training and awareness actions.

A plethora of decisions and documents have been produced throughout the more than 30 years of negotiation. With the creation of the Convention and the subsequent creation of mandatory greenhouse gas emission reduction targets for developed countries, the famous carbon market was born.

3 THE CARBON MARKET

The carbon market has emerged as a vital tool in global efforts to combat climate change, providing both economic incentives and a regulatory framework to reduce greenhouse gas emissions. As climate science has increasingly highlighted the urgent need for action, the carbon market has offered a mechanism through which governments, corporations, and even individuals can contribute to the reduction of emissions, while balancing economic development and environmental protection.

The basic premise of the carbon market is the "cap and trade" system. Under this model, a cap is set on the total allowable emissions for a given entity—whether a country, company, or sector. Entities that reduce their emissions below the cap are then able to sell the excess as carbon credits to others who may struggle to meet their own reduction targets. This system helps to ensure that overall emissions are reduced in the most cost-effective manner.

Two main carbon market systems exist: the compliance market, which is regulated by international agreements and governmental policies, and the voluntary market, which allows companies and individuals to offset their emissions without being legally obligated to do so. Both systems play complementary roles in the effort to mitigate climate change, though they operate with different mechanisms and participants.

3.1 Unlocking the Carbon Market: Initial Steps Towards Understanding

In a world increasingly aware of the environmental impacts caused by human activities, the carbon market emerges as one of the most innovative and promising tools to address the challenge of climate change. This mechanism, which may seem abstract at first glance, has a very concrete and potentially transformative application: it provides an economic means to reduce global greenhouse gas emissions.

As governments, companies, and societies seek solutions to achieve sustainability, the carbon market offers a viable path to finance greener practices and technologies, balancing economic development with environmental conservation. The relevance of this market in the current scenario is amplified by the growing scientific and public consensus on the urgency to act in mitigating greenhouse gas emissions, making it essential to understand its functioning, history, and impact.

This section and the following parts of this report will explore the fundamentals of the carbon market, investigating not only what it represents but also how it operates and why it has become a crucial component in global climate mitigation strategies. We will discuss the regulatory foundations shaping the market, the emerging technologies transforming the sector, and how different carbon pricing schemes are being implemented worldwide. We will delve into how these market mechanisms incentivize emission reductions, promoting a cleaner and more sustainable economic transition. This knowledge is vital for shaping a future where economic growth and environmental preservation work in harmony.

3.2 Understanding the Carbon Market

The carbon market is an economic system designed to reduce global greenhouse gas (GHG) emissions efficiently and economically. This market operates on the principle of "cap and trade," where a cap is set on the maximum number of certain gases that can be emitted by companies, governments, or other entities. Those that are able to reduce their emissions below the established limit can sell the surplus in the form of carbon credits to others struggling to meet their emission reduction targets (UNFCCC, 2008).

To explore the concept of the carbon market, it is essential to understand the difference between the two main operational systems: the market regulated by the United Nations Framework Convention on Climate Change (UNFCCC) and the voluntary carbon market. Both play important roles in combating climate change, but they operate with different guidelines and objectives.

In the regulated market, countries are divided into two groups based on their historical responsibilities for emissions and their emission levels at the time of the creation of the UNFCCC. Developed countries (called as Annex 1 parties) have committed to mandatory emission reduction targets, while developing and underdeveloped countries (called as non-Annex 1 parties) do not have mandatory targets but can participate by helping Annex 1 countries meet their goals through the generation of carbon credits via mitigation projects.

This concept gave rise to the carbon market, where a country (or a company, in the case of the voluntary market) that needs to reduce its emissions can buy carbon credits from another country (or company, farmer, industry, etc.) that has managed to generate these credits by reducing its own emissions. Figure 3 illustrates a theoretical representation of both the regulated and voluntary carbon markets.

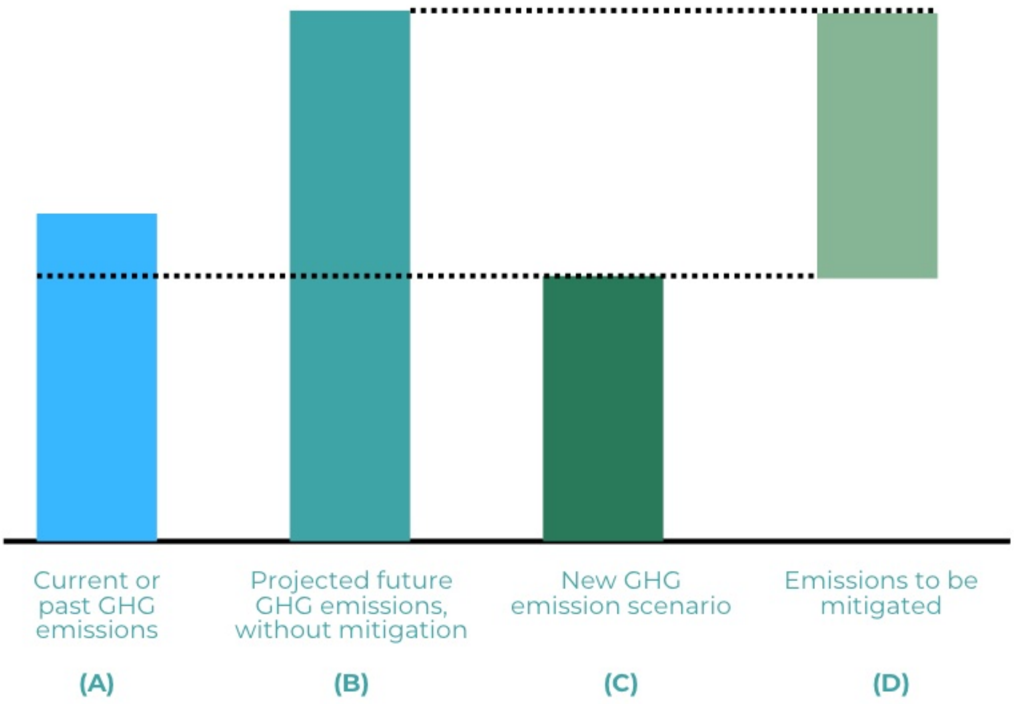

Figure 3: Theoretical carbon market scheme showing baseline emissions (A), projected emissions without mitigation (B), target emissions (C), and emissions to be mitigated (D).

- Scenario (A) represents the current or past GHG emissions of a country or company, serving as the baseline for future comparisons.
- Scenario (B) projects future emissions without considering any type of mitigation, showing what emissions would look like if no action is taken to reduce them.
- The (C) bar shows the new emissions scenario that the country or company must reach within a specific time frame (such as the 2030 or 2050 targets set by many countries and companies).
- The (D) bar illustrates the amount of GHG emissions that the country or company needs to mitigate in order to meet the established reduction target.

This schematic representation (Figure 3) is applicable to both the regulated and voluntary markets. It helps visualize the emission reduction process, where mitigation targets encourage countries and companies to invest in sustainable solutions, significantly contributing to climate change mitigation.

To understand better the idea behind the Carbon Market, it is important to assess the theory. The theoretical model of the carbon market is based on the idea that greenhouse gas (GHG) emissions and carbon sequestration must be carefully balanced to mitigate climate change. Figure 4 shows two distinct curves: the blue line representing the "Business as Usual" (BAU) scenario and the green and yellow lines representing scenarios A and B, respectively.

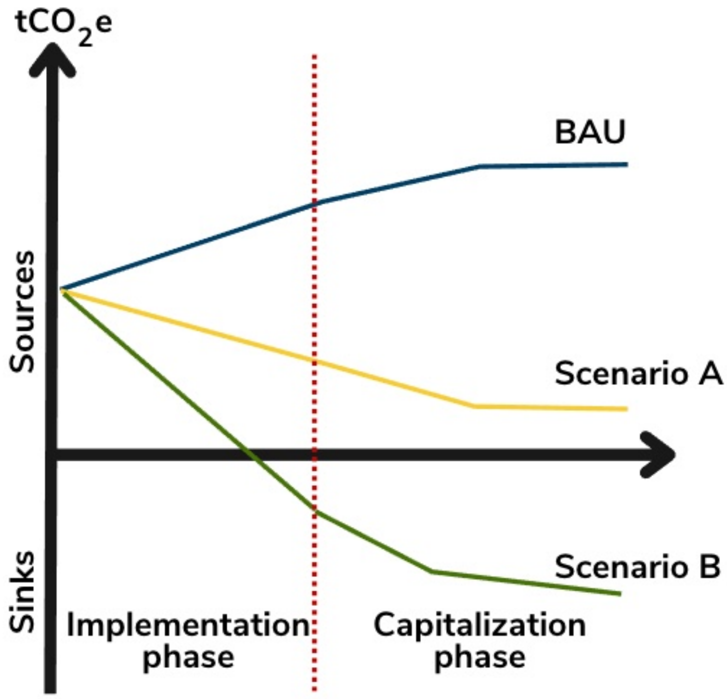

Figure 4: Theoretical model of the Carbon Market – This graph compares the Business-as-Usual (BAU) scenario with two mitigation scenarios (A and B). Scenario A shows moderate emissions reduction, while Scenario B highlights more aggressive emission cuts leading to carbon sequestration (sinks). The transition from the implementation to capitalization phase is marked by the red dotted line.

In the BAU scenario, emissions would continue to grow without the implementation of mitigation projects, resulting in an upward curve reflecting the increase in emissions over time. This scenario does not contemplate changes in current practices and serves as a reference point for measuring the impact of mitigation strategies.

Scenarios A and B, on the other hand, represent the implementation of carbon projects aimed at reducing emissions or increasing carbon sequestration. Scenario A could represent, for example, the adoption of renewable energy technologies or changes in agricultural practices that result in an immediate reduction of emissions (shown by the sharp decline of the yellow line). Scenario B could involve long-term strategies such as reforestation projects or integrated crop-livestock-forest systems that gradually increase carbon sequestration over time (as indicated by the green curve moving further away from the BAU line).

The area between the BAU curves and scenarios A and B represents the amount of emissions reduced or carbon sequestered. These differences are quantified and converted into carbon credits that can be sold or traded in the carbon market. The "Implementation Phase" indicates the period where mitigation actions begin to take effect, while the "Capitalization Phase" illustrates when these actions stabilize and start generating sustainable economic returns, either through direct cost savings or the sale of carbon credits.

This theoretical model not only exemplifies how carbon projects can alter the trajectory of GHG emissions but also highlights the economic nature of these environmental interventions in the context of the carbon market. By promoting and implementing such projects, an economic opportunity is created for climate change mitigation, demonstrating how economics and ecology can work together for a more sustainable future.

3.3 UNFCCC Regulated Market

The regulated carbon market, also known as the compliance market, is established and governed by international agreements under the aegis of the UNFCCC, including the Kyoto Protocol (UNFCCC, 1997; UNFCCC, 2008) and the Paris Agreement (UNFCCC, 2015) . This market is characterized by strict rules and mandatory emission reduction targets for participating countries, especially developed countries.

The Kyoto Protocol, signed in 1997, was the first major international accord that established binding emission reduction targets for developed countries, collectively known as Annex 1 countries. Under this agreement, countries were allocated specific amounts of allowable emissions, which could be traded between those that exceeded their limits and those that managed to reduce their emissions below the cap.

As part of the Kyoto Protocol, the Clean Development Mechanism (CDM) was introduced. This mechanism allowed developed countries to invest in emission reduction projects in developing countries and receive carbon credits in return. These credits could be used to meet their domestic emission targets, while also promoting sustainable development in the host countries. The CDM was a significant innovation, as it created a global market for carbon credits and provided an economic incentive for developed countries to finance clean technologies in the developing world.

The compliance market expanded with the signing of the Paris Agreement in 2015. Unlike the Kyoto Protocol, which imposed obligations only on developed countries, the Paris Agreement involves both developed and developing nations in the fight against climate change. Each country sets its own emission reduction targets, known as Nationally Determined Contributions (NDCs), which reflect their individual capacities and circumstances. The flexibility of the Paris Agreement allows for greater global participation, though it also means that enforcement mechanisms are less rigid than under the Kyoto Protocol.

The objectives of this market are linked to the commitments made by countries in international agreements, mostly established during the Conferences of the Parties (UNFCCC, 1997; UNFCCC, 2008). Participants are mainly national entities or large greenhouse gas emitters that are legally required to meet specific emission quotas.

In the regulated market, emission allowances are often distributed by the government to participants based on historical emission levels or through an auction process. Companies that reduce their emissions beyond their quotas can sell the surplus as carbon credits. Those that fail to meet their targets must buy credits to offset their excess emissions.

3.4 Voluntary Carbon Market

The voluntary carbon market allows companies, local governments, organizations, and individuals to purchase carbon credits on their initiative without legal obligation. This market is primarily driven by corporate commitments to sustainability, social responsibility, or internal carbon neutrality goals (UNFCCC, 2023).

In contrast to the compliance market, the voluntary carbon market operates outside the realm of international regulations. It is driven by corporate and individual initiatives to offset emissions as part of sustainability commitments, brand reputation management, or corporate social responsibility (CSR) programs. In the voluntary market, companies and organizations purchase carbon credits to neutralize their emissions, even if they are not legally required to do so.

The origins of the voluntary carbon market trace back to California, a place known for its pioneering approach to environmental issues. My Nuffield individual trips to San Francisco and Los Angeles revealed the innovation driving this movement from the beginning. In California, I could see how the voluntary market developed alongside the state’s strong regulatory framework but with a different mindset: rather than waiting for policies, companies and individuals took proactive steps to offset emissions as part of their own sustainability goals. This approach was built on the belief that market-based solutions could both drive economic value and environmental progress without direct government mandates. Understanding this history firsthand helped me grasp the principles that have shaped the voluntary market, especially the role of consumer and corporate responsibility in reducing emissions.

The Nuffield experience was transformative for me, as it opened my eyes to this distinct, proactive side of carbon markets. Coming from a background heavily grounded in regulated markets and government policies, my time in California allowed me to see how the voluntary market operates on different motivations and drivers. The journey helped me shift my own perspective: I realized that while regulated markets are crucial, there is a huge potential in voluntary systems where stakeholders move faster and can innovate more. This experience expanded my understanding of carbon markets, highlighting how both approaches - regulated and voluntary - play essential roles in tackling climate change.

Projects that generate carbon credits in the voluntary market often focus on reforestation, renewable energy development, and methane capture. However, increasingly, methodologies designed for agricultural land management are gaining attention, as agriculture is a key sector for carbon sequestration. Among these, VM0042 stands out as a critical methodology that provides a structured pathway for adopting sustainable agricultural practices and generating carbon credits.

<u>VM0042 Methodology: Agricultural Land Management for Carbon Credits:</u>

VM0042 is a methodology under the Verified Carbon Standard (VCS) that enables agricultural land management (ALM) practices to be converted into measurable and certifiable carbon credits. The core objective of VM0042 is to encourage sustainable farming practices that enhance carbon sequestration in soils and biomass, thus reducing greenhouse gas (GHG) emissions while simultaneously improving agricultural productivity. This methodology opens up new opportunities for farmers, to adopt regenerative practices and contribute to the carbon market. Under this methodology, several specific ALM practices are elegible:

Improved Crop Management: This includes crop rotation, cover cropping, and reduced or no-till farming, which collectively improve soil structure and increase organic matter content. By enhancing soil health, these practices contribute to long-term carbon storage in the soil, making it a more effective carbon sink.

Agroforestry Systems: The integration of trees and shrubs into agricultural landscapes is another practice encouraged under VM0042. Agroforestry systems sequester carbon both above and below ground, in the form of tree biomass and root systems, while also providing shade, preventing soil erosion, and enhancing biodiversity.

Improved Grazing Management: For livestock operations, the methodology emphasizes rotational grazing, which improves pasture health, increases carbon sequestration in soils, and enhances water retention. In regions where livestock farming is a dominant land use, such as the Brazilian Cerrado, this practice can lead to significant carbon savings.

Nutrient Management: Optimizing fertilizer use is another critical component of VM0042. By reducing the over-application of nitrogen-based fertilizers and adopting organic alternatives, farmers can reduce nitrous oxide emissions, a potent GHG, while improving soil fertility and crop yields.

Each of these practices must be carefully monitored, and their carbon sequestration potential quantified through a baseline scenario analysis, which VM0042 helps to structure. A baseline is established by assessing current agricultural practices and their associated GHG emissions. The improvements made through sustainable practices are then compared to this baseline to determine the additional carbon sequestered.

Certification and Verification Under VM0042

One of the strengths of VM0042 is its robust verification process. Projects must adhere to strict monitoring and reporting protocols, ensuring that the carbon credits generated are real, measurable, and additional—meaning that the reductions or sequestration would not have occurred in the absence of the project. This verification is performed by third-party certifiers accredited by the VCS, who ensure the project's integrity and that the credits issued represent genuine environmental benefits.

The process includes:

Baseline Assessment: Establishing a clear picture of the emissions and sequestration capacity under traditional agricultural practices.

Monitoring Plan: Defining key metrics for carbon sequestration, such as soil organic carbon, tree biomass, and crop productivity.

Reporting and Auditing: Detailed annual reports are submitted to the VCS, documenting the project's progress, emissions reductions, and carbon sequestration. Audits are conducted to verify that the practices implemented are in line with the approved methodology.

The VM0042 methodology, like other VCS methodologies, ensures transparency and accountability, which is crucial for maintaining the credibility of the voluntary carbon market. By adopting this methodology, farmers and landowners can access the voluntary carbon market, selling credits to companies that wish to offset their emissions and contribute to global sustainability goals.

The Growth of Agricultural Carbon Credits in the Voluntary Market:

In recent years, there has been significant growth in the use of VM0042 and similar methodologies as the agricultural sector becomes increasingly integrated into the voluntary carbon market. As companies recognize the value of agricultural carbon credits—not only for reducing emissions but also for promoting sustainability across supply chains—the demand for such credits has risen sharply. This shift is particularly notable in sectors that rely heavily on agricultural inputs, such as the food and beverage industry, where companies are looking to reduce their scope 3 emissions by investing in sustainable agriculture.

Benefits of VM0042 for Farmers and the Environment:

VM0042 offers significant benefits for farmers, the environment, and the carbon market. By encouraging the adoption of sustainable agricultural practices, it allows farmers to increase productivity and resilience in the face of climate change, while simultaneously generating an additional revenue stream through carbon credits. For the environment, the widespread adoption of VM0042 can result in improved soil health, increased biodiversity, and reduced GHG emissions.

Moreover, the voluntary carbon market serves as an important complement to the compliance market, allowing for broader participation in emission reduction efforts. As consumers become more conscious of the environmental impacts of their purchasing decisions, companies are increasingly looking to offset their carbon footprints by supporting projects that adhere to methodologies like VM0042. This not only boosts the credibility of the voluntary market but also drives innovation and progress in sustainable land management.

In conclusion, VM0042 provides a structured and scientifically validated pathway for farmers and landowners to engage in the voluntary carbon market. By adopting sustainable practices such as agroforestry, improved grazing, and crop management, participants can generate carbon credits while contributing to global efforts to combat climate change. This methodology bridges the gap between agriculture and climate action, offering a practical solution for addressing some of the most pressing environmental challenges of our time.

3.5 Origins and Historical Evolution

The concept of the carbon market is firmly rooted in the growing recognition of the adverse impacts of climate change triggered by human activities that elevate greenhouse gas emissions and their concentrations in the atmosphere, consequently leading to global temperature rise and various other climatic effects. This mechanism was developed as a strategic response to mitigate these effects by incentivizing the reduction of these gases in an economically feasible manner.

Discussions on climate change and its implications began gaining global prominence over five decades ago. However, it was after the United Nations Conference on Environment and Development (Rio92) held in Rio de Janeiro in 1992 that these concerns crystallized into a formal framework with the creation of the United Nations Framework Convention on Climate Change (UNFCCC). This event marked a decisive turning point, establishing an international forum dedicated exclusively to discussing and combating climate change through coordinated global initiatives (Mendes, 2014).

The UNFCCC served as a catalyst for a series of international negotiations and agreements, culminating in the Kyoto Protocol in 1997, which introduced quantifiable and legally binding emission reduction targets for developed countries, wich conferring real regard to the human influence on climate UNFCCC, 1997; Oppenheimer et al., 2007). The Kyoto Protocol was innovative in instituting market mechanisms such as the Clean Development Mechanism (CDM), which allowed developed countries to meet their emission targets by purchasing carbon credits generated from emission reduction projects in developing countries.

The evolution continued with the adoption of the Paris Agreement in 2015 during COP 21. This agreement reinforced the need for global climate action, establishing the goal of limiting global temperature rise to well below 2°C above pre-industrial levels and striving to limit the increase to 1.5°C, recognizing this as crucial for protecting ecosystems and global biodiversity (UNFCCC, 2015).

These treaties and agreements not only formalized countries' commitment to reducing carbon emissions but also established the carbon market as a fundamental instrument for achieving such reductions cost-effectively, encouraging the adoption of clean technologies and sustainable practices on a global scale.

3.6 Comparison Between the Two Markets

While both the compliance and voluntary carbon markets aim to reduce GHG emissions, they differ in terms of their structure, participants, and regulatory frameworks. The compliance market is governed by international agreements and is legally binding, meaning that participants must adhere to specific emission reduction targets or face penalties. This market is more predictable and structured, as the demand for carbon credits is driven by legal obligations.

In contrast, the voluntary market is more flexible and less regulated. It is driven by companies and individuals who choose to offset their emissions for reasons such as corporate social responsibility, brand reputation, or personal values. The voluntary market is often seen as more innovative, as it allows for a wider range of projects and participants, including smaller organizations and individuals.

Despite these differences, the two markets are complementary. The compliance market provides the foundation for large-scale emission reductions, particularly in high-emission sectors such as energy and heavy industry. The voluntary market, on the other hand, engages a broader range of participants and fosters innovation in emission reduction projects.

3.7 The Economics of Carbon

Carbon finance is an economic measure aimed at effectively solving the climate problem (Liu et al., 2015), is a term referring to the financial activities supporting the reduction of CO2 emissions. It involves policy research on carbon emissions, the product design of carbon financial derivatives, and setting carbon emission prices and carbon rations. It plays a vital role in adjusting the energy structure and governing contemporary climate change (Wang, et al., 2022; Li and Li, 2011), which is different from the traditional financial activities.

Specifically, carbon finance refers to the many kinds of trading activities and related financial policies for reducing GHG emissions, including the trading and investment of carbon emission rights and their derivatives, investment and financing for the development of low-carbon projects, and other related financial intermediary activities (Wang et al., 2022). Carbon market is the place for these financial transactions, including all the institutional arrangements and policy systems. The establishment and development of carbon market is of great significance for solving the capital problems of low-carbon economic development, improving the carbon emissions trading system and enhancing the core competitiveness of a national economy (Luo et al., 2016).

Carbon credits are a vital financial instrument in the carbon market, with the primary goal of incentivizing the reduction of greenhouse gas emissions economically. Each credit represents one metric ton of carbon dioxide equivalent that has been avoided or sequestered from the atmosphere through sustainable projects such as low-carbon agriculture, reforestation, renewable energy, among others.

The economic value of carbon credits arises from the need for companies and governments to comply with environmental regulations or achieve voluntary sustainability targets. By purchasing credits, these entities can offset their emissions, fulfilling their obligations more flexibly and cost-effectively than if they had to reduce all their emissions directly. This mechanism not only encourages the development and implementation of environmentally friendly technologies but also generates revenue streams that can support local communities and fund new conservation and carbon reduction projects.

The carbon market plays a crucial role in the transition to a green economy, especially in developing countries where financial resources for investments in clean technologies and sustainable practices may be limited. By enabling sustainable projects to generate revenue through the sale of carbon credits, this market provides a vital economic incentive for sustainable development.

In developing countries, the carbon market offers a dual opportunity: it contributes to economic growth while promoting environmental management. Projects financed through carbon credits can improve local quality of life by creating jobs, transferring technologies, and promoting the sustainable use of natural resources. Additionally, these projects often bring additional benefits such as biodiversity preservation, protection of vital ecosystems, and support for local communities, aligning economic development with environmental conservation.

Therefore, the carbon market is not just an economic adjustment mechanism; it is an essential tool for promoting sustainability. It supports the achievement of the United Nations Sustainable Development Goals (SDGs) and strengthens the resilience of emerging economies against the impacts of climate change. By valuing and monetizing carbon reduction, the carbon market incentivizes the adoption of sustainable practices crucial for the planet's future and the prosperity of populations in less developed regions.

As we advance our understanding of the carbon market, it becomes evident that it is not merely a financial mechanism but a key component in global sustainability strategies. The implications of an effective carbon market are vast, extending beyond simple mitigation of greenhouse gas emissions. It represents an opportunity to redefine economic and environmental practices, integrating them in ways that benefit both the economy and the environment.

The economics of carbon, with its ability to translate carbon reductions into tangible economic value, has the potential to leverage significant transformations in industrial sectors and local communities, especially in developing countries. However, this transformative potential is deeply dependent on the structures and operational mechanisms governing the carbon market, which need to be robust, transparent, and fair to facilitate equitable participation.

The carbon market has evolved into a powerful tool for combating climate change, providing both economic incentives and regulatory frameworks for reducing GHG emissions. As the world moves toward a low-carbon economy, the carbon market will play a critical role in facilitating the transition. By aligning economic growth with environmental sustainability, the carbon market offers a path forward for countries and companies to achieve their climate goals.

3.8 The Trajectory of the Carbon Market and Its Strategic Importance

In the previous sections, we embarked on an in-depth journey through the carbon market, unveiling its foundational mechanics and the challenges and innovations that define its current operation. We observed how technology and policy can leverage efficiency and transparency and how innovative initiatives and smart regulations are essential for overcoming barriers and expanding global participation.

Now, as we approach the horizon, we turn our eyes towards the future to understand the direction in which the carbon market is heading and the significant role it will play. "The Trajectory of the Carbon Market and Its Strategic Importance" is more than a glimpse into emerging trends; it is a recognition of the market's ongoing influence on the fabric of global environmental policy and the promotion of a sustainable economy.

At the heart of this section, we will explore not only market expectations and potential growth directions but also how the carbon market is becoming increasingly integrated into business strategy and public policy planning. This chapter invites us to consider the carbon market as a fundamental catalyst for the energy transition and for achieving the ambitious climate goals that lie ahead.

Laying the groundwork for the discussions to emerge, we investigate the strategic importance of the carbon market for the future: how it can adapt, scale, and innovate to meet the needs of a changing world. In this context, every perspective, development, and innovation tell part of the story of how we can collectively address one of the greatest challenges of our time.

3.9 The Carbon Market and Global Development Goals

The integration of the carbon market with global sustainability goals is more than a strategic alliance; it is a necessary fusion to drive change towards a more resilient and sustainable future. This market has been fundamental to achieving global objectives, acting as a bridge that connects environmental theory with tangible market practices.

At the intersection of economy and ecology, the carbon market is a tool that quantifies and monetizes emission reduction initiatives, allowing environmental efforts to translate into economic value. This economic alchemy makes sustainability not just an ideal but also a profitable and viable practice. With each carbon credit, we are a step closer to achieving vital goals such as those established in the Paris Agreement and the United Nations Sustainable Development Goals (SDGs).

Looking ahead, the carbon market is poised to profoundly influence both global policy and business practices. As environmental regulations become increasingly integrated into political agendas, the carbon market is likely to play a central role in shaping climate policies. Governments may turn to it as a mechanism to meet international commitments, while companies may see it as a pathway to sustainable innovation and a means to achieve corporate carbon reduction goals.

As the demand for climate action intensifies, businesses will be encouraged to incorporate carbon strategies into their business models not only to mitigate regulatory and reputational risks but also to capitalize on emerging opportunities in the green market. The carbon market is expected to be a compass that guides innovation, driving investments in clean technologies and sustainable practices, thereby shaping the next era of global business and sustainability.

3.10 Future Perspectives

Looking ahead to the coming decades, the carbon market positions itself as a key element in the evolution of our global climate and economic strategies. Figure 1 provides a window into current trends that signal a promising future for this expanding market. We observe impressive growth in the volume traded in the voluntary market, especially since 2020, reflecting a growing interest and collective commitment to mitigating climate change.

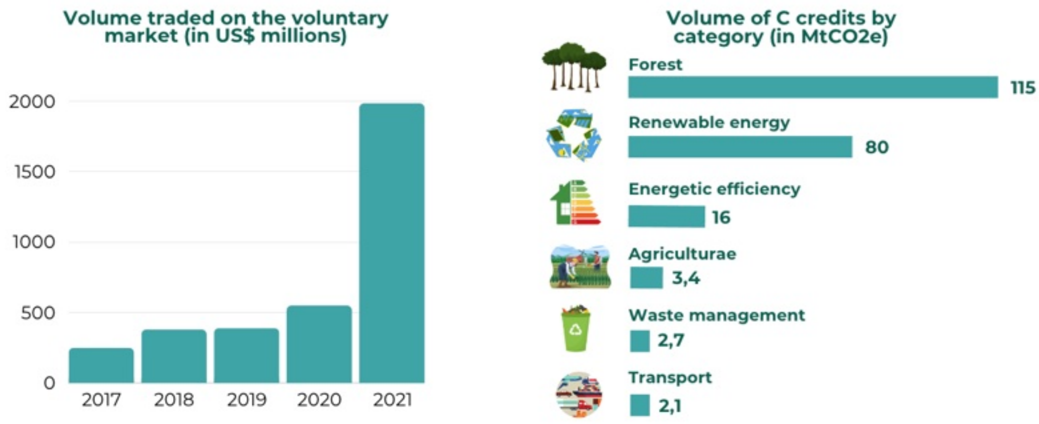

Figure 5: Voluntary carbon market in numbers.

In recent years, nature-based solutions (NbS) have increased significantly. These solutions contribute to improving the functions of ecosystems and landscapes affected by polluting and degrading activities. Improving, at the same time, the quality of natural resources and contributing to social and cultural well-being (Miralles-Wilhelm, 2023).

With NBS it is possible to simultaneously address issues related to: climate change and conservation of natural resources while maintaining productive agricultural systems. NBS can mimic natural processes and be based on operational land-water management concepts that aim to simultaneously improve water availability and quality and increase agricultural productivity (Griscom et al., 2017; Sonneveld et al., 2018; Muller et al., 2021).

Nature-based solutions, particularly projects focused on forests and increasingly on agriculture, emerge as vital frontiers for carbon credit development. Brazil is highlighted for its potential in these types of projects, driven by public policies such as the Low-Carbon Agriculture Plan (ABC Plan) that promotes low-carbon agriculture. This engagement with nature-based solutions is a trend expected to grow exponentially, contributing substantially to the carbon market in the coming decades.

The carbon market will experience unprecedented expansion in the coming years, with projections indicating an annual value of $100 to $120 billion in credit sales by 2030. Brazil, with its vast agricultural potential and commitment to sustainable practices, is poised to be one of the main players in this emerging market. Highlighting the agricultural sector, the country has the unique ability to meet up to half of this market demand, driving innovation and establishing a model for integrating sustainability and profitability in global agriculture. As the carbon market matures, these projections serve as a call to action for companies, investors, and governments.

Technological innovation will be a driving force for market expansion. As new tools and digital platforms make buying and selling carbon credits more efficient and transparent, the market is becoming more accessible to a wider range of participants. The scalability of these innovations will allow small projects and individuals to enter a field previously dominated by large entities, democratizing the market and increasing the volume of available carbon credits.

Additionally, the scalability of the carbon market will be driven by the integration of climate policies at national and international levels, expanding the scope and impact of existing initiatives and encouraging the emergence of new projects. With growing awareness of the urgency of climate action, we expect the carbon market to become an even more significant pillar in strategic business planning and public policy formulation, guiding the world towards a greener and more resilient economy.

My Nuffield individual trip to New York City for Climate Week was instrumental in broadening my understanding of the voluntary carbon market's growth potential and how Brazil is perceived globally. Attending discussions with global leaders and stakeholders gave me insights into the international perspective on Brazil’s vast agricultural potential and the challenges and opportunities it faces. It became evident that Brazil is seen as a pivotal player in the carbon market, particularly due to its capacity to scale nature-based solutions and sustainable agriculture. However, this also brings a responsibility to meet international standards for transparency and effectiveness in carbon credit generation.

This experience helped me realize the dual challenge Brazil faces: meeting the world’s expectations while navigating internal complexities to ensure equitable benefits for all stakeholders, especially farmers. The voluntary C market in Brazil with significant opportunities to lead in low-carbon practices, but it also requires a strong commitment to building robust certification systems that can validate sustainable practices on a global stage. This insight was invaluable, as it underscored both the potential and the steps needed to position Brazil as a leader in the evolving carbon economy.

In this trip, I had the opportunity to participate on very interesting events and had contact with important people from Brazil and other countries, as shown in the figures below:

Figura 6: Panel on Climate Solutions, hosted by TNC. In the photo: Helder Barbalho, Governor of Pará, John Kerry, United States Special Presidential Envoy for Climate; The Nature Conservancy's CEO, Jennifer Morris; and Fernando Haddad, Minister of Finance of Brazil. Also present at the event were Sonia Guajajara, Minister of Indigenous Peoples of Brazil, and Danielle Carreira, Financial Sector Engagement Lead at the Tropical Forest Alliance.

Figure 7: After the panel I had the unique opportunity to chat with Helder Barbalho, Governor of Pará.

I also had the opportunity to participate in the Forbes Sustainability Leaders Summit. The event was incredible, bringing together dozens of companies represented by their executives to discuss solutions for the planet's future. Following the summit, I was invited to a dinner hosted by Forbes and Cargill, where we discussed alternatives for agriculture and environmental preservation in Brazil and other countries.

Figure 8: Forbes Sustainability Leaders Summit at NY Climate Week 2023.

Figure 9: Dinner hosted by Forbes and Cargill

Figure 10: Izabela Teixeira, former Brazilian Minister of the Environment, and I at the Forbes and Cargill dinner.

Key Takeaways

As the carbon market expands and matures, the need for active participation from all sectors of society becomes increasingly evident. It is not merely a matter of environmental responsibility but a strategic opportunity that can catalyze large-scale socioeconomic transformations.

In Brazil, the potential for carbon market expansion is particularly significant. The vast expanse of agricultural land and unique biodiversity place the country in a privileged position to significantly contribute to global carbon mitigation. It is crucial that Brazilian rural producers, who are at the forefront of natural resource management, are encouraged and supported to actively participate in the market. This will not only improve the sustainability of their agricultural practices but also open new pathways for inclusive economic growth and rural development.

To stimulate this participation, it is imperative to promote an open and constructive dialogue about the opportunities and challenges of the carbon market. This dialogue should include rural producers, climate experts, political authorities, business leaders, and civil society. The goal is to create a space for continuous engagement where ideas can flow freely and where innovative strategies can be discussed and implemented.

Therefore, this is an explicit invitation for each individual and organization to recognize their role in this scenario and actively engage in shaping the future of the carbon market. Participating in this global conversation is a step forward in seeking practical and effective solutions to one of the greatest challenges of our time: climate change. Together, with commitment and collaboration, we can transform challenges into opportunities and guide Brazil and the world towards a greener and more prosperous path.

4 THE LOW CARBON AGRICULTURE IN BRAZIL

Brazil has long been a pivotal player in global agricultural production, contributing significantly to the global food supply. However, this has also positioned the country as a major emitter of greenhouse gases (GHGs), particularly from its agricultural sector. In response, Brazil has developed and implemented ambitious strategies to reduce GHG emissions and promote sustainable agriculture.

The use of good agricultural practices in Brazil has increased in recent years (Plano ABC). Government incentives such as the ABC Plan and the National ILPF Policy contribute not only to the implementation and dissemination of good agricultural practices, but also help to adapt to current environmental laws. Since, with the use of certain types of management, it is possible to recover environmental preservation.

This section explores the evolution and impact of Brazil's Low Carbon Agriculture (ABC) Plan, the strategic importance of integrating low carbon practices, and the future potential of these initiatives in contributing to global sustainability goals.

4.1 The ABC Plan and its Evolution: The Genesis and achievements of the ABC Plan

The ABC (Low Carbon Agriculture) Plan, launched in 2010, was Brazil's flagship initiative to align agricultural productivity with climate mitigation. The plan included various programs aimed at reducing GHG emissions through sustainable agricultural practices. Key technologies promoted under the ABC Plan included the recovery of degraded pastures, integration of crop-livestock-forest systems (ICLF), no-till farming, biological nitrogen fixation, planted forests, and the treatment of animal waste (Brazil, 2012). These practices not only aimed to reduce emissions but also to sequester carbon, enhancing soil health and productivity.

These efforts resulted in the mitigation of approximately 100.21 million Mg CO2 eq. The Brazilian commitment foresees a reduction of 36.1% to 38.9% of projected emissions by 2020, thus avoiding the emission of about 1 billion tons of CO2 equivalent (tCO2e), which represents the most significant reduction effort on the planet (Brazil, 2012).

The success of the ABC Plan can be measured by its widespread adoption and significant GHG mitigation. By 2018, the plan had led to the recovery of 4.46 million hectares of degraded pastures and the adoption of no-till farming on 9.97 million hectares. The ICLF systems exceeded their targets, covering 5.83 million hectares, and significantly contributing to carbon sequestration.

4.2 Transition to ABC+: New Goals and Strategies

Building on the success of the initial phase, the Brazilian government launched the ABC+ Plan (2020-2030) to further integrate low-carbon technologies into the agricultural sector. The ABC+ Plan sets more ambitious targets (table 1).

ABC+ Goals and mitigation 2021 to 2030			
Technologies	ABC+	Goals millions ha/m3/animals	Mitigations millions Mg CO2 eq
Recovery of degraded pastures		30	113.7
No-till systems	No-till for grains	12.5	12.1
	No-till for vegetables	0.08	0.88
Integrated systems	Integration Crop-Livestock-Forestry (ICLF)	10	34.1
	Agroforestry Systems (SAF)	0.1	37.9
Planted Forests		4	510
Bioimputs		13	23.4
Irrigated Systems		3	50
Management of animal production waste		208.4	277.8
Intensive termination		5	16.24
Total ABC+	72.68 million ha + 208.40 million m3 + 5 million animals		More than 1 million Mg CO2eq

Table 1: ABC+ goals and mitigation (Brazil, 2015).

The plan emphasizes innovation, increased financial support, and enhanced technical assistance to achieve these goals. Brazil's commitment to low carbon agriculture is integral to its Nationally Determined Contributions (NDCs) under the Paris Agreement. By adopting sustainable agricultural practices, Brazil aims to reduce its GHG emissions by 37% below 2005 levels by 2025 and by 43% by 2030 (Brazil, 2015).

The ABC+ Plan is a critical component of these efforts, positioning Brazil as a leader in integrating agricultural sustainability into national climate policies (Rodrigues, et al., 2019). The ABC+ Plan aims to consolidate low carbon agriculture as a cornerstone of Brazil's rural development strategy, promoting practices that simultaneously enhance productivity and environmental sustainability. This includes expanding the scope of technologies to encompass more precise and integrated approaches, leveraging digital agriculture, and fostering partnerships between public and private sectors.

4.3 Strategic Importance of Low Carbon Agriculture

Economic and Environmental Benefits:

Until the end of the last century, agriculture grew and developed based on expansion of new areas for cultivation, leading to the loss of large areas of native forests and natural ecosystems (ALEXANDRATOS; BRUINSMA, 2003), resulting in the loss of environmental services.

The use of agricultural inputs, mainly fertilizers, provided a large increase in crop productivity. This intensification of agricultural production, which occurred during the Green Revolution in the 1940s, also brought negative effects to the environment, such as: pollution of water, air and soil with pesticides and excess nutrients (SMITH et al., 2013c), increase in climate forcing (REAY et al., 2012), depletion of natural resources (CORDEL et al., 2009), use of large quantities of fossil origin (ERISMAN et al., 2008) and loss of habitats and biodiversity (FIRBANK et al., 2011).

With the continuous growth of the population and consequent pressure on natural resources and the growing demand for "ecologically correct" products, producing more and better has become essential. Therefore, within the context of agriculture, finding ways to increase productivity with minimal impact on the environment is one of today's greatest challenges.

Therefore, it is necessary to change the paradigm of agriculture with the use of management practices that favor the balance of physical and chemical attributes of the soil, such as increasing C, N content, water retention, reduction of soil loss through erosion and leaching.

The adoption of low carbon agriculture practices yields substantial economic and environmental benefits. Economically, these practices can increase productivity, reduce input costs, and open new revenue streams through carbon credits. Environmentally, they enhance biodiversity, improve water use efficiency, and contribute to climate resilience by maintaining soil health and reducing emissions

(Silva, et al., 2024; Oliveria et al., 2024; Ribiro et al., 2023; Silveira, et al., 2022; Polidoro et al., 2021; Conceição, et al., 2017; Moralles et at.,2023; Montagnini et al., 2021; Monteiro et al., 2024; Ribeiro et al., 2020).

The recovery of degraded pastures and ICLF, is a real way to achieve sustainable intensification of agricultural production. These technologies contribute to the mitigation of greenhouse gas emissions, increase productivity and income, increase social benefits to producers and consolidate sustainable development.

Key Takeaways

Sustained Commitment and Future Prospects:

The evolution from the ABC Plan to ABC+ reflects Brazil's sustained commitment to mitigating climate change through innovative agricultural practices. The success of these initiatives underscores the potential for agriculture to transition from being a major emitter to a significant carbon sink, contributing to global climate goals.

Economic and Environmental Synergy:

Low carbon agriculture not only supports Brazil's climate commitments but also provides a blueprint for integrating economic and environmental sustainability. By enhancing productivity and creating new economic opportunities, these practices demonstrate that sustainable agriculture is both feasible and beneficial.

Global Leadership and Replicability:

Brazil's experience with the ABC and ABC+ Plans offers valuable insights for other countries seeking to balance agricultural productivity with environmental sustainability. The scalable and adaptable nature of these practices makes them relevant beyond Brazil, contributing to global efforts to combat climate change and promote sustainable development.

In conclusion, Brazil's low carbon agriculture initiatives exemplify the potential of integrating sustainability into agricultural practices. As the ABC+ Plan unfolds, it promises to further cement Brazil's role as a global leader in sustainable agriculture, providing a model for others to follow and contributing significantly to the global fight against climate change.

My Nuffield individual journeys through Mato Grosso do Sul in Brazil and the Paraguayan Chaco were pivotal in deepening my understanding of the voluntary carbon market from the perspective of rural producers. Meeting directly with these producers, I gained insights into their expectations and challenges in navigating carbon market opportunities. Beyond the technical knowledge, this experience brought me closer to their realities, fostering empathy and a genuine understanding of their rationales. I realized that, for many of these producers, participating in the carbon market isn't just about additional revenue—it's about aligning with practices that secure long-term sustainability for their land and their communities.

Both regions hold immense potential for expanding sustainable agriculture through increased productivity, adoption of low-carbon technologies, and regenerative practices like crop-livestock integration. In particular, Mato Grosso do Sul and the Chaco offer large areas of underutilized or degraded land that can be transformed through efficient, low-carbon agricultural systems. Seeing firsthand the willingness of producers to engage in sustainable practices reinforced the importance of designing carbon market solutions that support their goals and realities. These regions could lead the way in showcasing how sustainable intensification in agriculture can drive carbon sequestration and economic growth, providing a model for other tropical regions around the world.

5 HOW TO USE THE POTENTIAL OF AGRICULTURAL LAND MANAGEMENT TO GENERATE INCOME UNDER CARBON MARKET

5.1 The Role of Agriculture in the Carbon Market: A Key to Global Sustainability

As we enter an era where sustainability is no longer an option but an imperative, agriculture emerges as a critical vector in the carbon market. Historically, the agricultural sector has been one of the largest contributors to greenhouse gas emissions, but this narrative is changing. Now, agriculture is being reconfigured as a potent solution to the climate crisis, promoting not only food security but also the health of our planet.

This section aims to dissect and illuminate the growing synergy between agriculture and the carbon market. The conversion of conventional agricultural practices to sustainable methods offers a tangible pathway for carbon capture, positioning the agricultural sector as a protagonist in the carbon economy. At the same time, climate change imposes unprecedented challenges on agriculture, influencing climate patterns and crop cycles. The result is a complex cycle where agriculture and climate are intrinsically linked—a cycle that, if properly managed, can strengthen the carbon economy and bring environmental, social, and economic benefits.

I invite you to explore this dynamic interaction with me as we delve into the opportunities that agriculture offers for carbon sequestration and how this aligns with global efforts to mitigate climate change. By doing so, we will reveal how agriculture is not only a fundamental piece in the tapestry of sustainability strategies but also an emerging economic pillar in the new green economy.

5.2 Agriculture and Climate Change

Agriculture, a pillar of the global economy, faces the challenge of being a significant source of greenhouse gas emissions, contributing notable amounts of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) (Rodrigues, et al., 2017; Torres et al., 2017). These emissions are the direct result of various practices, including enteric fermentation in ruminants, manure management, synthetic fertilizer use, and land conversion for agricultural use.

Emissions from agriculture drive a feedback cycle with the climate (Rodrigues, et al., 2017; Siva et al., 2018). On the one hand, agricultural practices intensify the greenhouse effect, altering ecosystems and reducing biodiversity. On the other hand, the impacts resulting from climate change, such as changes in precipitation patterns, extreme weather events, and rising temperatures, affect agriculture, threatening crop production and food security. This creates a cycle where agriculture contributes to climate change, which in turn challenges agricultural practices.

The volatility of food prices and the indirect costs related to health and climate adaptation are economic reflections of agricultural emissions. These emissions force farmers and rural communities to adapt practices and crop varieties, often with additional costs and technical requirements.

This delicate balance between agricultural practices and climate change highlights the urgent need for practices that not only reduce emissions but also strengthen the agricultural sector's resilience to climate changes. Fortunately, agriculture has enormous potential to transform from a net emitter to a significant carbon sink through carbon sequestration, promoting sustainable practices and contributing to the global carbon economy. By adopting more sustainable agricultural practices, the sector not only mitigates its own emissions but also helps combat climate change on a broader scale.

5.3 Potential of Agriculture for Carbon Sequestration

At the core of climate solutions, regenerative agriculture emerges as a powerful agent of change. Its practices not only slow greenhouse gas emissions but also promote carbon sequestration, capturing CO_2 from the atmosphere and depositing it in the soil, where it contributes to ecosystem health rather than global warming. Agricultural carbon sequestration can occur through a series of regenerative practices, such as:

<u>Crop-Livestock-Forest Integration (CLFI):</u> This synergistic approach combines crop production, livestock raising, and forest management in the same space, resulting in a more diversified and resilient production system. Besides sequestering carbon, this practice increases biodiversity, improves soil health, and optimizes the water cycle.

<u>No-Till Farming:</u> This technique involves planting new crops without tilling the soil, which keeps carbon trapped and reduces erosion. No-till farming, by decreasing soil disturbance, promotes microbial activity and soil structure, contributing to carbon fixation.

<u>Pasture Management:</u> Rotational grazing and targeted grazing mimic natural grazing patterns, leading to denser vegetation and carbon-rich soil. These practices not only sequester carbon but also improve pasture quality and productivity.

<u>Restoration of Degraded Pastures:</u> Through the restoration of lands that have suffered erosion, compaction, or fertility loss, it is possible to restore the soil's capacity to store carbon. This is often achieved through the planting of carbon-fixing plant species, improved water management, and the reintroduction of organic agricultural practices.

These techniques are not just theoretical but proven practices already being implemented in various regions, demonstrating that regenerative agriculture is viable and beneficial. By adopting carbon sequestration practices, farmers can play a crucial role in combating climate change while potentially benefiting from financial incentives such as carbon credits, which serve as monetary recognition of their contributions to global sustainability.

Key Takeaways

The integration of sustainable agricultural practices with the carbon market offers a unique opportunity to address climate change and promote environmental and economic resilience. By transitioning from conventional methods to regenerative practices, agriculture can transform from a major emitter to a significant carbon sink.

Agriculture's potential for carbon sequestration is vast and varied, with practices such as crop-livestock-forest integration, no-till farming, pasture management, and the restoration of degraded pastures offering practical and proven solutions. These methods not only reduce greenhouse gas emissions but also enhance soil health, biodiversity, and agricultural productivity.

As the carbon market continues to evolve and expand, the role of agriculture within it becomes increasingly important. The economic incentives provided by carbon credits can drive widespread adoption of sustainable practices, making agriculture a cornerstone of the global effort to mitigate climate change.

In conclusion, agriculture holds a pivotal role in the transition to a sustainable and low-carbon economy. By embracing regenerative practices, the agricultural sector can significantly contribute to carbon sequestration and the broader goals of global sustainability. The path forward involves continued innovation, collaboration, and commitment to integrating agricultural sustainability with the carbon market.

6 CASE STUDY – CARBON CREDITS POTENTIAL FROM A CONCEPT FARM IN THE BRAZILIAN CERRADO

6.1 Introduction

Brazil, with its vast agricultural lands and diverse ecosystems, plays a crucial role in global food production. The country's agriculture sector is not only pivotal to its economy but also to the global food supply chain. Brazil is a leading producer and exporter of a variety of agricultural commodities, including soybeans, corn, coffee, sugarcane, and beef. However, this agricultural prowess comes with significant environmental challenges, primarily due to deforestation, land-use changes, and unsustainable farming practices.

To address these challenges, Brazil has been at the forefront of integrating low carbon agricultural practices aimed at reducing emissions, enhancing carbon sequestration, and promoting sustainable development (Dos Reis, et al., 2023; Dos Reis et a., 2016; Rodrigues, et al., 2017; Siva et al., 2018; Denny et al., 2024).

This section delves into a case study of a fictitious farm in the Brazilian Cerrado, exploring theoretical scenarios for converting degraded pastures into regenerative agriculture and livestock systems. The study highlights the environmental and economic benefits of such conversions, illustrating their potential to contribute to global sustainability goals.

This case study explores the transition of a theoretical farm located in the Cerrado from conventional, degraded pasture management to a variety of integrated agricultural systems aimed at increasing carbon sequestration and reducing emissions. By focusing on the adoption of regenerative practices such as crop-livestock integration (ICL) and crop-livestock-forestry systems (ICLF), this study investigates how sustainable agriculture can be scaled to enhance both environmental and economic outcomes. The objective is to evaluate the carbon sequestration potential and GHG emissions reduction of these systems over a 10-year period and to understand the economic viability of adopting such approaches in the Cerrado.

The Cerrado offers a unique opportunity to implement regenerative agriculture practices that could significantly contribute to global climate goals. With its vast tracts of degraded pastureland, it is well-positioned for restoration efforts that can increase soil organic carbon, improve biodiversity, and enhance the livelihoods of local farmers. By integrating these systems, the Cerrado could also become a model for other tropical and subtropical regions seeking to balance agricultural productivity with environmental stewardship.

6.2 Methodology

To explore the carbon sequestration potential and economic viability of sustainable agricultural systems, this study uses a concept farm located in the Brazilian Cerrado. The farm covers 1,000 hectares, of which 35% (350 hectares) is designated as Legal Reserve (RL) and Areas of Permanent Preservation (APP), in compliance with the Brazilian Forest Code. The remaining 650 hectares are used for agricultural production.

The initial condition of the productive land is characterized by degraded pasture, with a stocking rate of 0.4 heads per hectare. This baseline scenario, referred to as the Business-as-Usual (BAU) scenario, is used as the reference point for comparison with four alternative management scenarios:

Baseline Scenario (BAU):

The BAU scenario represents the current state of degraded pasture with minimal intervention. Over time, this scenario is expected to result in further pasture degradation, leading to continued carbon loss, poor productivity, and high GHG emissions.

Scenario 1: Recovery of Degraded Pastures (RDP):

In this scenario, 2/3 of the productive area (433 hectares) undergoes moderate intensification, with an increase in stocking rate to 1.2 heads per hectare. Improved grazing management, including rotational grazing and the planting of forage species, is implemented. The remaining 1/3 (217 hectares) receives more intensive management, with a stocking rate of 2.4 heads per hectare. Fertilization with nitrogen and lime is applied to enhance soil fertility and productivity.

Scenario 2: Integrated Crop-Livestock (ICL):

In the ICL scenario, 325 hectares of the farm are dedicated to integrated crop-livestock systems, alternating between crop production (soybeans or maize) and pasture in a rotational cycle. This system increases soil organic carbon through the addition of crop residues and roots, while maintaining a stocking rate of 2.4 heads per hectare in the livestock areas. The other 325 hectares continue to follow the moderate intensification of pasture management as in Scenario 1.

Scenario 3: Integrated Crop-Livestock-Forestry (ICLF - in-line planting):

In this scenario, half of the productive area (325 hectares) is used for ICL systems, while the remaining 325 hectares integrate forestry by planting eucalyptus trees in line with pasture (167 trees per hectare). This agroforestry system aims to enhance carbon sequestration through tree biomass while maintaining the productivity of livestock and crops.

Scenario 4: Integrated Crop-Livestock-Forestry (ICLF - forest massif):

Similar to Scenario 3, this scenario incorporates agroforestry into half of the productive area (325 hectares), but with a higher density of tree planting (1,111 trees per hectare) in 81.3 hectares. The remainder of the land follows the same moderate pasture intensification as in Scenario 1.

Data Collection and Analysis:

Data for carbon sequestration and GHG emissions were collected from a combination of field studies, scientific literature, and agricultural models (especially Ex-Act from FAO) applicable to the Cerrado. Carbon sequestration was estimated using the IPCC Tier 2 approach, incorporating region-specific emission factors for Brazilian pastures, crops, and forestry systems.

Emission factors from livestock (methane from enteric fermentation), fertilizers (nitrous oxide), and soil carbon changes were calculated using established models (IPCC and Ex-Act). Economic analysis included the costs of implementing each system, the potential for revenue generation through carbon credits, and projected productivity increases.

6.3 Results

Carbon Sequestration:

The carbon sequestration potential of each scenario is depicted in Figure 6. Over the 10-year period, each scenario significantly outperforms the BAU in terms of net carbon sequestration:

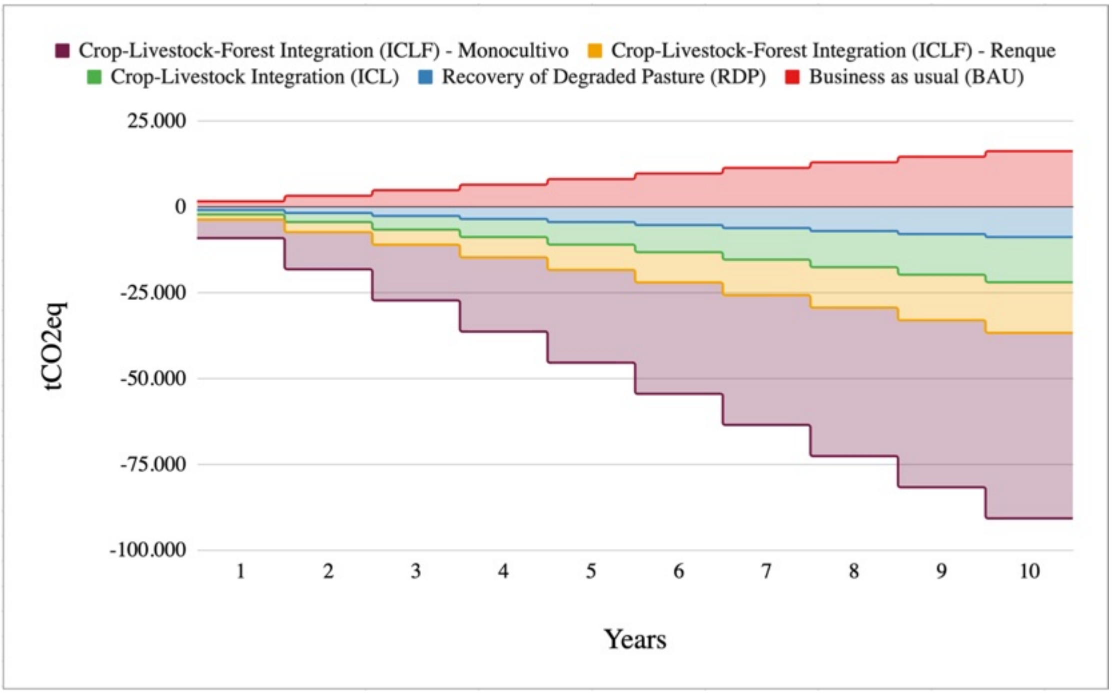

Figure 11: Net balance for the different scenarios.

BAU Scenario:

The BAU scenario results in continued carbon loss due to degraded pasture conditions, with no net carbon sequestration. By year 10, this scenario leads to further depletion of soil organic carbon and contributes approximately +10,000 tCO2eq of GHG emissions annually.

Scenario 1 (RDP):

The recovery of degraded pastures begins to show positive results by year 2. Over the 10-year period, the RDP scenario achieves cumulative carbon sequestration of approximately -25,000 tCO2eq, as improved grazing management enhances soil carbon storage and reduces erosion.

Scenario 2 (ICL):

The introduction of crop rotation in the ICL system accelerates carbon sequestration, reaching -50,000 tCO2eq by year 10. The integration of crops with livestock improves soil organic matter and nutrient cycling, contributing to long-term carbon storage.

Scenario 3 (ICLF - in-line planting):

With the inclusion of forestry, the ICLF scenario significantly boosts carbon sequestration potential, with cumulative carbon sequestration of around -75,000 tCO2eq by year 10. The addition of tree biomass plays a key role in this increase.

Scenario 4 (ICLF - forest massif):

Scenario 4, which integrates high-density tree planting, achieves the highest cumulative carbon sequestration of all scenarios, exceeding -100,000 tCO2eq by year 10. The extensive tree cover enhances both biomass and soil carbon storage, making this the most effective system in terms of carbon capture.

<u>GHG Emissions Reduction</u>

All sustainable scenarios show significant reductions in GHG emissions when compared to the BAU scenario. In Scenario 1, methane emissions from livestock are reduced by improving pasture quality and forage availability. Scenarios 2, 3, and 4 further decrease emissions by integrating crops and trees, which enhance nutrient cycling and soil health, reducing the need for synthetic fertilizers.

Scenario 1: Methane and nitrous oxide emissions are reduced by approximately 20% due to improved pasture management.

Scenario 2: Emissions are reduced by 35%, primarily due to increased crop rotation, which reduces the reliance on fertilizers.

Scenario 3 & 4: Emissions are reduced by over 50%, as tree planting offsets methane emissions and increases carbon storage in both biomass and soil.

Economic Outcomes

The economic analysis shows that all four sustainable scenarios outperform the BAU in terms of profitability. Scenario 1 demonstrates modest increases in productivity, while Scenarios 2, 3, and 4 introduce diversified income streams, including revenue from crop production, livestock, timber sales, and potential carbon credits.

Scenario 1 (RDP): Moderate increases in productivity result in a 15% increase in profitability compared to BAU.

Scenario 2 (ICL): Diversified income from crops and livestock leads to a 30% increase in profitability.

Scenario 3 (ICLF - in-line planting): Timber sales and carbon credits contribute to a 45% increase in profitability.

Scenario 4 (ICLF - forest massif): With the highest levels of timber production and carbon credits, Scenario 4 achieves a 60% increase in profitability, making it the most economically viable option.

6.4 Discussion

This case study highlights the transformative potential of regenerative agriculture in the Brazilian Cerrado, where degraded pastures can be converted into productive, carbon-sequestering systems. The integration of crop, livestock, and forestry practices offers a scalable solution to both environmental and economic challenges. By enhancing soil health, increasing biodiversity, and reducing GHG emissions, these systems provide a comprehensive approach to sustainable farming.

A key aspect of this transformation is the potential for farms adopting these regenerative practices to generate carbon credits through participation in formal carbon markets. With proper certification, farms that implement practices such as agroforestry, integrated crop-livestock systems, and the recovery of degraded pastures can quantify their carbon sequestration and sell carbon credits to organizations seeking to offset their emissions. This additional income stream has the potential to make sustainable agriculture financially attractive for producers, helping to cover the costs of transitioning to regenerative systems while generating long-term environmental benefits.

In addition to carbon credits, the adoption of these systems provides several other environmental, economic, and social benefits. Environmentally, improved soil health, increased biodiversity, and enhanced water retention all contribute to the resilience of agricultural systems in the face of climate change. From an economic perspective, farms that adopt regenerative practices can access premium markets through sustainability certifications, add value to their products, and benefit from diversified income streams. Socially, the transition to low-carbon agriculture promotes the capacity-building of farm workers, creates new employment opportunities in rural areas, and can contribute to local development by boosting farm profitability and increasing local tax revenues.

The scalability of this process is particularly important for Brazil, a country with approximately 90 million hectares of degraded pastures. If regenerative agricultural systems like those described in this case study were implemented at scale, the country could significantly contribute to global climate mitigation efforts. Large-scale adoption of such practices would enable Brazil to reduce its agricultural emissions while enhancing food security, preserving biodiversity, and contributing to rural economic development.

6.5 Conclusion

This study demonstrates the significant environmental and economic benefits of transitioning from degraded pastures to regenerative agricultural systems in the Brazilian Cerrado. The results show that integrating livestock, crops, and forestry can lead to substantial carbon sequestration, reduced GHG emissions, and improved farm profitability. The findings underscore the need for continued research and policy efforts to scale these practices, not only in Brazil but also in other tropical and subtropical regions facing similar challenges.

Moreover, the potential for generating carbon credits through formal carbon market projects provides an additional income stream for farmers, making the transition to regenerative agriculture economically viable. Beyond financial returns, these practices offer a wide array of benefits, including improved soil health, enhanced biodiversity, better water retention, and increased resilience to climate change. The economic advantages extend to value-added products, sustainability certifications, and access to differentiated markets, which further enhance the farm’s competitive position.

Socially, regenerative agriculture contributes to the training of farm workers, the creation of jobs, and the development of rural economies. At a national scale, the implementation of these practices across Brazil's 90 million hectares of degraded pastures holds immense potential to transform the country’s agricultural landscape. By promoting sustainable farming systems, Brazil could enhance its contribution to global climate goals, support rural communities, and safeguard its rich biodiversity for future generations.

7 GENERAL CONCLUSIONS

This report has explored the intersection of agricultural land management and the carbon market, particularly in the context of Brazil's role as a global agricultural powerhouse. By focusing on regenerative agricultural practices, such as the integration of crops, livestock, and forestry, the report has demonstrated how Brazil's agricultural systems can shift from being a source of greenhouse gas emissions to becoming a significant contributor to climate change mitigation.

Key conclusions drawn from the report include:

- Carbon Market Opportunities: The integration of agriculture into the carbon market provides a tangible opportunity for farmers to both reduce their environmental footprint and access new revenue streams. Carbon credits, generated through practices like reforestation, improved grazing management, and crop-livestock-forest integration, can be monetized, offering farmers a financial incentive to adopt sustainable practices. However, access to these markets is still limited for many producers due to bureaucratic and technical barriers.
- Regenerative Agriculture as a Key Solution: The adoption of regenerative practices in farming systems—such as the recovery of degraded pastures, crop rotation, agroforestry, and silvopastoral systems—has proven to enhance soil carbon sequestration, improve soil health, and increase biodiversity. These systems not only contribute to climate change mitigation but also provide economic resilience, boosting productivity and reducing input costs in the long term.
- Environmental Co-benefits: In addition to carbon sequestration, regenerative agriculture offers numerous environmental benefits, including improved water retention, enhanced soil structure, increased biodiversity, and better resilience to climate change impacts. By restoring degraded land and promoting sustainable farming practices, these systems help reverse the negative effects of land degradation, particularly in the Brazilian Cerrado, a biome highly vulnerable to unsustainable land use practices.
- Economic and Social Advantages: Beyond the direct environmental benefits, the report highlights the economic potential of low-carbon agriculture. Farmers who adopt regenerative practices can diversify their income sources by integrating timber, livestock, and crops, while accessing premium markets through sustainability certifications. Socially, these practices contribute to job creation, capacity-building, and increased local economic activity, particularly in rural areas where agriculture plays a pivotal role in community development. These transitions have the potential to increase the quality of life for farmers and farm workers alike, contributing to broader rural development and local economic growth.

- Potential for Large-Scale Impact: With an estimated 90 million hectares of degraded pastures, Brazil has enormous potential to scale up regenerative practices. If managed correctly, this process could position Brazil as a global leader in low-carbon agriculture, making substantial contributions to global climate change mitigation goals. By restoring degraded lands, the country can enhance its agricultural output sustainably while contributing to biodiversity preservation, rural economic development, and climate change mitigation.
- Challenges and Barriers: While the potential for regenerative agriculture is clear, several barriers remain. These include a lack of access to technical knowledge and financial support, regulatory complexity around carbon credit certification, and the need for stronger policy frameworks that encourage sustainable practices. Addressing these challenges is essential for scaling these systems and ensuring their long-term viability.

Overall, the report concludes that regenerative agriculture, combined with access to carbon markets, offers a clear pathway for sustainable agricultural development. With the right support, Brazil’s agricultural sector can contribute meaningfully to both environmental and socio-economic goals, helping to mitigate climate change while enhancing rural livelihoods.

8 RECOMMENDATIONS

To unlock the full potential of regenerative agriculture and the carbon market, several critical actions must be taken by policymakers, industry leaders, and farmers. These recommendations address not only the barriers identified in this report but also propose pathways to ensure that agriculture in Brazil—and similar regions worldwide—can thrive in a sustainable and climate-positive future.

Expand Access to Carbon Markets:

- Governments and industry stakeholders must simplify the processes for farmers to access carbon markets. This includes streamlining certification processes and reducing the bureaucratic burden on small and medium-sized farms.
- Promoting the development of locally relevant carbon market standards, tailored to the Brazilian context, can help smaller producers participate in these markets. Partnerships between private sector actors and government bodies could establish better frameworks for integrating smallholders into the carbon credit system.
- Technical assistance programs should be expanded to help farmers quantify and verify carbon sequestration on their land, ensuring that they can fully capitalize on the benefits of carbon trading.

Provide Financial and Technical Support:

- Public and private financing initiatives should be developed to support farmers during the transition to regenerative agricultural practices. These could include grants, subsidies, low-interest loans, and tax incentives aimed at facilitating initial investments in infrastructure, technology, and training.
- Technical support must be made more widely available, through both public extension services and private initiatives. Capacity-building programs are crucial to teaching farmers the best practices in regenerative agriculture, as well as how to monitor and report their carbon sequestration activities.

Strengthen Policy Frameworks:

- Policymakers should work to strengthen existing frameworks like the ABC+ Plan, focusing on ensuring that sustainable agriculture is both accessible and economically viable for producers. Policies that reward the adoption of low-carbon practices through financial incentives and market access will be essential for scaling these systems.
- Clear targets and metrics for carbon sequestration in agriculture should be integrated into Brazil's climate commitments under the Paris Agreement. By setting national goals for regenerative agriculture, Brazil can demonstrate leadership in sustainable food systems while advancing its climate change mitigation efforts.

Support Innovation and Research:

- Continued investment in research and development (R&D) is necessary to refine carbon accounting methodologies, develop region-specific solutions, and improve the efficiency of regenerative agricultural practices. Universities, research institutions, and the private sector should collaborate to promote innovation in areas such as soil health, crop rotation techniques, and agroforestry models.
- Pilot programs should be developed to test and showcase the scalability of regenerative systems in different parts of the country. These pilots could serve as case studies for further research and development, helping to create replicable models that can be applied at scale.

Promote Public-Private Partnerships:

- Collaboration between government, industry, and non-governmental organizations will be critical to scaling regenerative agriculture in Brazil. Public-private partnerships can drive investment in infrastructure, capacity-building, and technological innovation, while fostering multi-stakeholder dialogue to address the complex challenges faced by the agricultural sector.
- Creating national and regional platforms where stakeholders can share knowledge and best practices will enhance the dissemination of successful models and encourage greater adoption of sustainable farming practices.

Foster Market Access and Certification:

- Farmers adopting sustainable practices should be encouraged to pursue certifications that can grant them access to premium markets. Programs that certify the sustainability and low-carbon impact of agricultural products can help farmers secure higher prices for their goods and enter differentiated markets.
- Additionally, connecting farmers to global markets that prioritize sustainability, such as organic and fair-trade markets, can drive further adoption of these practices by ensuring that economic returns are maximized.

Leverage Brazil's Global Leadership Potential:

- With its vast agricultural landscape and strong history in climate diplomacy, Brazil is well-positioned to become a global leader in low-carbon agriculture. Scaling the implementation of regenerative practices across the estimated 90 million hectares of degraded pastures can offer both environmental and economic benefits on an unprecedented scale.
- Brazil should use its leadership role in international climate negotiations to promote regenerative agriculture as a key solution for other tropical and subtropical regions, sharing its successes and advocating for global policies that support low-carbon farming systems.

By addressing these key areas, Brazil can fully unlock the potential of regenerative agriculture, driving significant environmental, economic, and social benefits. The adoption of these practices not only enhances the sustainability of the agricultural sector but also creates a roadmap for other nations to follow as they seek to balance food production with climate resilience.

REFERENCES

ALEXANDRATOS, N.; BRUINSMA, J. (2003) Introduction and overview. In: BRUINSMA, J. (Ed.). World Agriculture: Towards 2015/2030, an FAO Perspective. London: Earthscan Publications, 2003. p. 1-28.

B. Asadieh, B.; Krakauer, N.Y., (2017). Global change in streamflow extremes under climate change over the 21st century. *Hydrological. Earth System Science*. Retrieved from: 10.5194/hess-21-5863-2017

Berger, A., (2002). The Milankovitch astronomical theory of paleoclimates: A modern review. *Science Direct.* Retrieved from: doi:10.1016/0083-6656(80)90026-4

Brazil, 2012. Brazil's Nationally Appropriate Mitigation Actions
Brazil. Retrieved from: <https://unfccc.int/files/focus/mitigation/application/pdf/brazil_namas_and_mrv.pdf>. Acesso em: 25 out. 2019

Brazil, 2015. Brazil Intended Nationaly Determined Contribution (INDCs). Retrieved from: <https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20iNDC%20english%20FINAL.pdf>.

Bredin, D., Hyde, S., Mucley, C.., 2014. A microstructure analysis of the carbon finance market. *International Review of Financial Analysis*. Retrieved from: :10.2139/ssrn.1899227

ClimateWatch, 2024. Global Historical Emissions. Retrieved from: https://www.climatewatchdata.org/ghg-emissions?end_year=2021&start_year=1990

CONCEIÇÃO, M. C. G., Matos, E. S., Bidone, E. D., Rodrigues, R. A. R., Cordeiro, R. C. (2017), Changes in Soil Carbon Stocks under Integrated Crop-Livestock-Forest System in the Brazilian Amazon Region. *Agricultural Sciences*. Retrieved from:.https://doi.org/10.4236/as.2017.89066

Cordell, D.; Drangert, J.O., White, S. The story of phosphorus: global food security and food for thought. Global Environmental Change, v. 19, p. 292–305, 2009.

Cred & UNDRR, 2020: The Non-COVID Year in Disasters: Global trends and perspective. Retrived from: https://www.undrr.org/media/49057/download?startDownload=20240913

Denny, D. E M. T., ; Cerri, C E. P. ; Cherubin, M. R. ; Burnquist, H. L. (2024). Nature-Based Solutions: Sustainable Development of Latin America. *Green and Low-Carbon Economy*. Retrieved from: https://doi.org/10.47852/bonviewGLCE4202888

Reis, J. C. ; Kamoi, M. Y. T. ; Michettil, M. ; Wruck, F. J. ; Rodrigues, R. A. R. ; Farias Neto, A. L. (2023). Economic and environmental impacts of integrated systems adoption in Brazilian agriculture-forest frontier. *Agroforestry Systems.* Retrieved from: 10.1007/s10457-023-00831-5

Reis, J. C. ; Rodrigues, R. A. R. ; Da Conceição, M. C. G.; MARTINS, C. M. S. (2016) Integração Lavoura-Pecuaria-Floresta no Brasil: uma estratégia de agricultura sustentável baseada nos conceitos da Green Economy Initiative. *Sustentabilidade em Debate.* Retrieved from: 10.18472/SustDeb.v7n1.2016.18061

Erisman, J.W.; Sutton, M. A.; Galoway, J.; Klimont, Z.; Winiwarter, W. (2008). How a century of ammonia synthesis changed the world. *Nature Geoscience.*

Firbank, L. et al. Enclosed farmland. In: UK National Ecosystem Assessment. Understanding nature's value to society: Technical Report. Cambridge: UNEP-WCMC, 2011. p. 197–239.

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., (2017). Natural climate solutions. Earth, Atmospheric and Planetary Science. Retrieved from: doi: 10.1073/pnas.1710465114

Haigh, J. D. (2003). The effects of solar variability on the Earth's climate. Philosophical Transactions Royal Society A, *Mathematical, Physical and Engeneering Sciences*.Retrieved from: https://doi.org/10.1098/rsta.2002.1111

Indermühle, Andreas; Monnin, Eric; Stauffer, Bernhard; Stocker, Thomas F; Wahlen, Martin (2000a): A high-resolution record of the atmospheric CO2 concentration from 60-20 kyr BP from the Taylor Dome ice core, Antarctica [dataset]. *PANGAEA*, Retrieved from: https://doi.org/10.1594/PANGAEA.710905,

Indermühle, A, Monnin, E., Stauffer, B., Stoucker, T. F., Wahlen, M. (2000b): Atmospheric CO2 concentration from 60 to 20 kyr BP from the Taylor Dome ice cores, Antarctica. Geophysical Research Letters, Retrieved from: https://doi.org/10.1029/1999GL010960

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. Retrieved from: DOI:10.1017/CBO9780511546013

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. Retrieved from: https://www.ipcc.ch/report/ar5/wg1/

IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., Retrieved from: doi:10.1017/9781009325844.

Li, X.N. and Li, Y.F. (2011) Diving Forces on China's Circular Economy: Form Government's Perspectives. *Energy Procedia*. Retrieved from: https://doi.org/10.1016/j.egypro.2011.03.051

Liu, L., Chuxiang, C., Zhao, Y., Zhao, E. (2015). China's carbon-emissions trading: overview, challenges and future. *Renewable and Sustainable Energy Reviews*. Retrieved from: 10.1016/j.rser.2015.04.076

Luo, C., Wu, C. (2016). Environment and economic risk: an analysis of carbon emission market and portfolio management. *Environmental Research*. Retrieved from: https://doi.org/10.1016/j.envres.2016.02.007.

Mendes, T. A., (2014). Desenvolvimento sustentável, política e gestão da mudança global do clima: sinergias e contradições brasileiras. Brasília: Universidade de Brasília. Retrieved from: http://www.realp.unb.br/jspui/handle/10482/17168

Miralles-Wilhem, 2023. Nature-based solutions in agricultural landscapes for reducing tradeoffs between food production, climate change, and conservation objectives. *Frontiers in Water.* Retrieved from: https://doi.org/10.3389/frwa.2023.1247322

Montagnini, F., Ibrahim, M. A., Murgueitio, E. (2013), Silvopastoral systems and climate change mitigation in Latin America. *Bois et Forêts des Tropiques*. Retrieved from: https://www.researchgate.net/publication/286770717_Silvopastoral_systems_and_climate_change_mitigation_in_Latin_America

Monteiro, A., Barreto - Mendes, L., Fanchone, A., Morgavi, D. P., Pedreira, P. C., Magalhães, C. A., Abdalla, A. L., Eugène, M. (2024), Crop-livestock-forestry systems as a strategy for mitigating greenhouse gas emissions and enhancing the sustainability of forage-based livestock systems in the Amazon biome. *Science of the Total Environment*. Retrieved from: https://doi.org/10.1016/j.scitotenv.2023.167396

Morales, M. M., Tonini, H., Belhing, M., Hoshide, A. K. (2023), Eucalyptus Carbon Stock Research in an Integrated Livestock-Forestry System in Brazil. *Sustainability*. Retrieved from: https://doi.org/10.3390/su15107750

Muller, L., Eulenstein, F., Dronin, N. M., Mirschel, W., McKensie, B. M., Antrop, M., et al. (2021). "Agricultural landscapes: history, status and challenges," in Exploring and Optimizing Agricultural Landscapes. Innovations in Landscape Research, eds L. Mueller, V. G. Sychev, N. M. Dronin, and F. Eulenstein (Cham: Springer). Retrieved from: doi: 10.1007/978-3-030-67448-9_9

Oliveira, D.M.S. ; Cerri, C. E. P. ; Cherubin, M.R. (2024). Crop, livestock, and forestry integration to reconcile soil health, food production, and climate change mitigation in the Brazilian Cerrado: A review. *Geoderma Regional.* Retrieved from: https://doi.org/10.1016/j.geodrs.2024.e00796

Oppenhueimer, M., B.C. O'Neill, M. Webster and S. Agrawala (2007). The Limits of Consensus. *Science*.Retrieved from: http://dx.doi.org/10.1126/science.1144831

Petit, J., Jouzel, J., Raynaud, D. et al. (1999). Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature.* Retrieved from: https://doi.org/10.1038/20859

Polidoro, J. C. ; Freitas, P. L. ; Hernani, L. C. ; Anjos, L. H. C. ; De Aragão Ribeiro Rodrigues, R. ; Cesário, F. V. ; Andrade, A. G. ; Ribeiro, J. L. . (2021). Potential impact of plans and policies based on the principles of Conservation Agriculture on the control of soil erosion in Brazil. Land Degradation & Development. Retrieved from: 10.1002/ldr.3876

Ribeiro, J. M., Freitas, I. C., Brito., B. G. S., Fernandes, L. A., Leite, L. F., Barbosa, D. L A., Santos, m. V., Cerri, C. E. P., Frazão, I. A. (2023). Agrosilvopastoral system as a potential model for increasing soil carbon stocks: a century model approach. *Revista Brasileiras de Ciência do Solo.* Retrieved from: https://www.scielo.br/j/rbcs/a/KxSGXjv4G33NxnZSbzgKrLq/?lang=en

Reay, D. S., Davidson, E. A., Smith, K. A., Smith, P. (2012). Global agriculture and nitrous oxide emissions: challenges of estimation, projection and mitigation. *Nature Climate Change*. Retrieved from: 10.1038/nclimate1458

Ribeiro, I. C. F., Martins, J., Araújo, N., santos, M., Sampaio, R. A., Fernandes, L. A., Azevedo, A., Feigl, B. J., Cerri, C. E. P., Frazão, I. A. (2020), Agrosilvopastoral Systems and Well-Managed Pastures Increase Soil Carbon Stocks in the Brazilian Cerrado. *Rangeland Ecology & Management.* Retrieved from: https://doi.org/10.1016/j.rama.2020.08.001

Rodrigues, R. A. R.; Conceição, M. C. G.; Bidone, E. D.; Matos, E. S.; Cordeiro, R. C.; SELVA, G. V.(2019). The actions of the Brazilian agricultural sector in the context of climate change negotiations. *Sustentabilidade em Debate*. Retrieved from: https://doi.org/10.18472/SustDeb.v10n2.2019.26238.

Rodrigues, R. A. R.; de Mello, W.Z. ; Guilles, M. C. ; de Souza, P. A. ; Silva, J. J. N. (2017). Nitrogen Dynamics in Tropical Agricultural and Forest Systems and their Impact on Climate Change. *Revista Virtual de Química*. Retrieved from: 10.21577/1984-6835.20170110

Silva, J. J. N. ; de Mello, W.Z. ; De Aragão Ribeiro Rodrigues, R. ; Alves, B.,J. R. ; de Souza, P. A. ; Guilles, M. C. (2018). Nitrogen Cycling in Tropical Forests and Eucalyptus Plantations in Brazil in the Anthropocene. *Revista Virtual de Química*. Retrieved from: 10.21577/1984-6835.20180118

Silva, L.; Oliveira, D.; Santos, R., Oliveira, P., Freitas, D.,Cherubin, M., Cerri, C(2024). Soil carbon dynamics in integrated agricultural systems in Minas Gerais state, Brazil: A meta-analysis. *Geoderma Regional.* Retrieved from: https://doi.org/10.1016/j.geodrs.2024.e00761

Silveira, J. G. ; Wink, C. ; Cesário, F. V., Armacolo, N. ; Nogueira, A. K. S. ; Silva, J. J. N. ; Leite, F. F. G.; Conceição, M. C. G. ; Oliveira Neto, S. N. ; De Aragão Ribeiro Rodrigues, R.(2022). Understanding the flux of nitrous oxide from the eucalypt soil in monoculture and Integrated Crop Livestock Forest Systems. *Australian Journal of Crop Science*. Retrieved from: 10.21475/ajcs.22.16.01.p3372

Smith, P., Mike R. Ashmore, Helaina I. J. Black, Paul J. Burgess, Chris D. Evans, Timothy A. Quine, Amanda M. Thomson, Kevin Hicks, Harriet G. Orr . (2013). The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology.* Retrieved from: https://doi.org/10.1111/1365-2664.12016

Sonneveld, B. G., Merbis, J. S., Alfarra, M. D. A., Ünver, O., and Arnal, M. A. (2018). Nature-Based Solutions for Agricultural Water Management and Food Security. FAO Land and Water Discussion Paper no. 12. Rome: FAO, 66. Retrived from: http://www.fao.org/3/CA2525EN/ca2525en.pdf

Torres, C. M. M., Jacovine, L. A. G; Oliveira Neto, S. N., Fraisse, c. W., Soares, C. P. B., Neto, F. C., Ferreira, L. R., Zanuncio, J. C., Lemes, P. G. (2017). Greenhouse gas emissions and carbon sequestration by agroforestry systems in southeastern Brazil. *Nature Scientific Reports*. Retrieved from: DOI:10.1038/s41598-017-16821-4

UNFCCC, 1992. United Nations Framework Convention on Climate Change. Retrieved from: <https://unfccc.int/sites/default/files/conveng.pdf>.

UNFCCC, 1998. United Nations Framework Convention on Climate Change.Kyoto Protocol to the United Nations Framework Convention on Climate Change. Retrieved from: https://unfccc.int/kyoto_protocol?gad_source=1&gclid=CjwKCAjwxY-3BhAuEiwAu7Y6s5Ytjzf1pLNgCDWRWJEB-rUAen_8wEZcHRNackzbO4KGFnvFo8r2PBoC0a8QAvD_BwE

UNFCCC, 2015. United Nations Framework Convention on Climate Change. Paris Agreement, 2015. Retrieved from: <https://unfccc.int/sites/default/files/english_paris_agreement.pdf>

UNFCCC, 2023. Reginal Climate Week: Introduction to internacional voluntary carbon markets. Retrieved from: https://unfccc.int/sites/default/files/resource/Session%204%20Introduction%20to%20International%20VCMs.pdf

UNFCCC, 2024. Clean Development Mechanism: CDM Project Cycle. Retrieved from: https://unfccc.int/process-and-meetings/the-kyoto-protocol/mechanisms-under-the-kyoto-protocol/the-clean-development-mechanism?gad_source=1&gclid=CjwKCAjwxY-3BhAuEiwAu7Y6s6srKA2OGNT8bLvQGizK1VQTeWdFKSiRP2vyfJm3xx-2G81g9i5myxoC5esQAvD_BwE

USGS, (2024). Science for a changing world. Volcanoes Can Affect Climate. Retrieved from: https://www.usgs.gov/programs/VHP/volcanoes-can-affect-climate#:~:text=Volcanic%20gases%20react%20with%20the,potential%20to%20promote%20global%20warming.

Wang, Z., Wei, Y., Wang, S. (2022). Exploring the research situation of carbon finance: A scientometric analysis on Web of Science database. *Journal of Climate Finance*. Retrieved from: 10.1016/j.jclimf.2022.100003

Annex I

GFP Journey:

A Transformative 28-Day Experience Across 5 Countries!

From March 18 to April 13, 2024, I set out on a truly transformative journey: the Global Focus Program (GFP). Over 28 days, I traveled across Brazil, the United States, Germany, Northern Ireland, and Ireland, alongside 10 other scholars from seven different countries. Together, we immersed ourselves in a rich tapestry of agricultural practices, exploring diverse challenges, innovations, and opportunities in each region. This experience was far more than just an educational program—it was a rare, once-in-a-lifetime journey that broadened my perspective and deepened my understanding of global agriculture.

I'll try to share here some of this incredible experience that NuffieldBR International Farming Network, Nuffield International, and Nuveen, a TIAA company provided to me.

Brazil: Exploring the Roots of Innovation

Our adventure started in Brazil, with visits to some of the country’s most influential agricultural companies and cooperatives. From SLC Agrícola’s headquarters in Porto Alegre to Nova Aliança Vinícola in Flores da Cunha, we gained insights into the growth of Brazilian agriculture over the last 50 years. These visits emphasized how far Brazil has come, showcasing cutting-edge technology, resilience, and the warmth of its people. The stops at RAR in Vacaria, known for its Grana Padano cheese and impressive apple production, and Agroindústria Carraro’s organic food production highlighted Brazil's capacity for diverse, sustainable agriculture. The welcome and hospitality were touching and unforgettable. And it was very rich to see the impressions from my colleagues about my country.

Day 1: 03/18/2024

- **Visit to SLC Agrícola headquarters in Porto Alegre, RS**
  We had the privilege of listening to Frederico Logemann share the amazing story of one of Brazil's largest companies. It was impressive to learn about the company's numbers and its incredible growth, which has greatly contributed to the development of Brazilian agriculture. Hearing about the challenging early days in Rio Grande do Sul and the technological advancements, as well as the saga of occupying the Midwest (which I witnessed closely during my years in Sinop), really highlighted Brazil’s agricultural evolution over the past 50 years.
- **Visit to Nova Aliança Vinícola Coop. in Flores da Cunha, RS**
  This is one of Brazil's top five wineries, with almost 100 years of history. Its story is closely tied to the development of Brazilian winemaking. The cooperative has 700 member families and processes around 50 million kg of grapes annually for various types of juice and wine. Beyond the amazing tour, we were received with such warmth and hospitality—it was truly touching! We even received personalized wine bottles as a gift! Huge thanks to Heleno Facchin and the incredible team at the cooperative.

Figure 1: The whole “GFP gang” plus other Nuffield colleagues that were in the post-CSC

Figure 2: Meeting at SLC Agrícola.

Figure 3: Visit to Nova Aliança Vinícola Coop

Day 2: 19/03/2024

- **Visit to RAR headquarters in Vacaria/RS:** We had the opportunity to learn about the inspiring history of RAR and taste their amazing products. The highlight was the fantastic Grana Padano cheese—the first to be produced outside of Italy using the original recipe. I always buy it in Rio de Janeiro, but sampling it inside the aging chamber was an extraordinary experience! The process of producing 140 tons of this incredible cheese each month starts much earlier, with the confined dairy cows. The farm has 3,000 cows, of which 1,300 are in lactation, with an average yield of 35 liters per cow per day. Milking is done with industrial precision and a lot of technology, ensuring high productivity and animal welfare, along with various water and waste recycling techniques. In addition to cheese, RAR cultivates 1,300 hectares of apples, with yields of up to 70 tons per hectare. It was fascinating to learn about the different apple production systems, and the impact of climate change on this crop was striking! The El Niño event of 2023/2024 devastated the apple industry, dropping Brazil's average productivity to 25 tons per hectare. Moreover, increasingly frequent and intense hailstorms are driving up production costs, as orchard coverage becomes necessary. The rising frequency and severity of these events are pushing part of Vacaria's apple production to higher elevations, particularly in São Joaquim/SC.
- **Visit to Agroindústria Carraro, in Vacaria/RS:** This organic food production site, which processes over 65 products including juices, jams, sauces, and sweets, has been operating organically since 1993, and officially became a family agro-industry in 2003. They also run a restaurant (where we enjoyed delicious food made by the owner). The farm is part of the "Agroecological Circuit," a network of over 2,000 farms in southern Brazil and São Paulo that helps organize production and features distribution centers spread throughout the region. This initiative aims to bridge the gap between rural and urban areas, reducing transportation costs and delivering products to consumers faster and more efficiently. The owners shared that their biggest challenges in organic production are Brazilian regulations and the frequent changes in government programs with each presidential transition. They are hopeful about the revival and growth of PNAE and PAAS but also highlighted difficulties in participating in these programs due to excessive bureaucracy and labor shortages.

Figure 3: Visit to RAR company and fields.

Figure 4: Visit to RAR company and fields.

Figure 4: Visit to RAR company and fields.

Figure 4: Lunch at an Organic restaurant that belongs to a small farmer.

Day 3: 20/03/2024

- **Visit to Sementes Com Vigor:** We were introduced to the company by Pedro Basso, a third-generation family member. Pedro's grandfather purchased the farm in 1958 and began growing soybeans in 1962. By 1969, they had started producing seeds and established their own brand. Pedro's father, Raul Bastos, was a pioneer of no-till farming in Brazil and continues to be a strong advocate for the practice, along with other sustainable farming techniques such as crop rotation, which he introduced in the 1980s. The company also applies precision agriculture across 100% of its area, resulting in more uniform fields and better-standardized seeds. Currently, they produce seeds of oats, peas, buckwheat, radish, wheat, beans, and soybeans.

Day 4: 21/03/2024

- **Visit to Dália Alimentos:** This cooperative was founded in 1947 by 387 pork producers seeking better market conditions for their products. In 2024, Dália Alimentos reached 2,625 member families who produce pork, chicken, and milk. These products now account for 40%, 10%, and 50% of the cooperative's annual revenue of 382 million BRL, respectively. It was fascinating to learn more about the cooperative members' production systems and the highly professional operations of the cooperative itself.

Day 5: 22/03/2024

- **Visit to CEAGESP:** We were thoroughly impressed by the scale and organization of CEAGESP (https://ceagesp.gov.br/), the largest food distribution center in Latin America. In 2023, the center handled over 3 million tons of products, including fruits, vegetables, fish, and flowers. On average, 50,000 people—ranging from suppliers and employees to buyers—pass through the center daily, along with 12,000 vehicles. In addition to its permanent shops, CEAGESP hosts specialized markets for fish, fruits, and fresh produce at specific locations and times. Beyond the incredible operation, we were warmly welcomed by the team, with the visit coordinated by Adrielle Melero. The team even produced a great video of the visit, providing more information about the NuffieldBR International Farming Network: https://lnkd.in/dpkzARTX

Figure 5: Visit to Sementes Com Vigor

Figure 6: Visit to Sementes Com Vigor

Figure 5: Visit to Ceagesp.

Texas, USA: Eye-Opening Agricultural Scale

In Texas, we encountered American agriculture on a grand scale. The state's production numbers are staggering, and the lack of widespread sustainability practices was a revelation. It was also interesting to note how knowledgeable Texans are about Brazilian agriculture and their awareness of Brazil's role as a competitor in global markets. Visiting with the team from Agoro Carbon Alliance US gave us a glimpse into the carbon market's potential and challenges. Their work with farmers in the voluntary C market underscored the importance of sustainable practices and the value they add to agricultural products.

From March 23rd to 30th, I was in Texas with 10 other scholars from 6 different countries (Australia, New Zealand, Poland, England, Ireland, and the USA), visiting farms, research and extension institutions, government agencies, and various businesses.

It was very interesting to learn more about agricultural production in the USA, especially in Texas. The state has some truly impressive numbers, being the largest producer among all American states for 14 agricultural products (some like beef and dairy were expected, but I was surprised by others, like citrus and pecans).

Other points that really caught my attention include:

- The lack of sustainability practices, not only in the countryside but also in the cities. The use of plastics is absurd, as is the use of chemical products in the crops (we often heard about the lack of consumer interest in organics, and that this is even a political issue);
- 90% of the land in the state is privately owned, and 87% of it is productive! There are no indigenous reserves or conservation units. Even with high rates of erosion and water issues (excess rain in the east and drought in the west of the state), there's no discussion about reforesting riverbanks.
- Their knowledge and concern about Brazil! From farmers to employees of the state's Department of Agriculture, they are very aware of Brazil's agriculture and see our growth as one of the biggest challenges for them in the coming years.

We had many discussions on various topics related to production itself and other related subjects like water, sustainability, and the carbon market.

It was interesting to understand that even here, with a more consolidated carbon market in agriculture (though not so much in Texas), producers still have many doubts and concerns.

However, they are also excited, and it was very insightful to speak with the team from Agoro Carbon Alliance US, which is doing a great job educating producers and including them in the projects (Texas is the third state with the largest area in Agoro's project, behind only Nebraska and Montana).

The projects in this area are growing, and the interest from producers is very high, not just for generating credits and income but also for associating a positive image with their activities and adding value to their products.

The opportunities for Brazil are also huge, mainly due to the vast potential for additionality that we can achieve through the recovery of degraded pastures and the adoption of low-carbon technologies, particularly in Crop-Livestock Integration and Crop-Livestock-Forestry systems.

It was also great to visit the Texas A&M Agrilife Research and Extension Center in Stephenville and Tarleton State University and see pecan trees over 300 years old. And of course, we ate a lot of barbecue.

Figure 6: The GFP participants and our American hosts at the Texas and Southwestern Cattle Raisers Association expo.

Figure 7: The amazing and huge Pecan trees from Texas.

Figure 8: At Tarleton State University, with some students. I had the opportunity to share some knowledge about Brazil and they did a presentation to the rest of the class.

Germany: Precision and Innovation

Germany impressed us with its highly efficient agricultural sector, backed by government subsidies, advanced technology, and a strong commitment to sustainability. Yet, the challenges are real: water management, land costs, and climate change pressures. One highlight was meeting a German farmer who had visited Brazil to learn about no-till farming, recognizing our expertise in sustainable practices. Germany's dedication to sustainable farming and overcoming economic barriers showed us that agriculture can be both productive and eco-conscious.

The third week of the GFP from NuffieldBR International Farming Network and Nuffield Farming Scholarships Trust, with support from Nuveen, a TIAA company, took place in Germany. Another incredible experience, and these were my main impressions:

Germany's agricultural sector is among the most advanced in Europe, thanks to robust government subsidies and cutting-edge technology. These elements, along with a strong emphasis on education, research, and quality standards, have positioned German agriculture at the forefront of global food production. Regions like Bavaria, with its rich tradition in dairy and grains, and Eastern Germany, known for its vast arable land, play crucial roles in this system. However, the sector faces significant challenges. Water management, strict legislative frameworks, and the urgent need for sustainable practices are testing farmers' resilience. Climate change is also affecting the availability and quality of water, and as regulations become increasingly complex, farmers will need to rely heavily on technology and knowledge to ensure both productivity and compliance. I want to highlight the story of a producer who visited Brazil this year to, in his own words, "learn how to do no-till farming from the best agriculture in the world"! Moreover, the high cost of land in Germany presents a considerable barrier to entry for new farmers and the expansion of existing farms. This not only impacts the economic viability of agriculture but also affects the sector's potential for innovation. Germany’s dedication to overcoming these obstacles is significant. It’s not just about maintaining high standards of quality and efficiency; it’s also about ensuring the sustainability of practices that protect the environment for future generations.

Figure 9: A public building in Berlin.

Figure 10: At Horsch headquarters with Michael Horsch in person!

Figure 11: Strawberry production in a huge greenhouse.

Figure 12: Aspargus field production

Ireland & Northern Ireland: Sustainability in Action

Our final week took us to Ireland and Northern Ireland, where agriculture is central to the economy. We explored Ireland’s impressive dairy and beef industries, with most production going toward exports. Sustainability is a growing priority here, and institutions like Bord Bia are leading the way with sustainability certifications that strengthen the market. In Northern Ireland, we saw a similar focus on quality and environmental responsibility, with ambitious goals to cut emissions by 25% by 2030 and achieve Net Zero by 2050. The challenges from Brexit and market fluctuations were also evident, pushing the sector toward innovative solutions.

I had an incredible experience in Ireland and Northern Ireland, where I had the privilege of diving into the dynamics of local agriculture. We discussed issues such as exports, efficiency, productivity, reducing greenhouse gas emissions, and adapting to climate change. Agriculture is vital to the economy in these regions, despite its dependency on government subsidies.

🥛🐄 In the Republic of Ireland, the strength of the dairy and beef sectors is impressive. With 80% of production destined for export, Ireland positions itself as one of the giants in the export of milk and dairy products in the European Union. A visit to Bord Bia (https://www.bordbia.ie/) showed me how committed they are to promoting sustainable practices, operating in 14 countries, and strengthening the market with sustainability certifications.

🐑🌿 Meanwhile, in Northern Ireland, the intensity of agriculture, particularly in livestock and meat production (both cattle and sheep), highlighted the importance of quality and provenance, which are highly valued in both local and international markets.

🌍 The challenges are substantial, particularly regarding greenhouse gas emissions and sustainable practices. Both regions are being challenged to adopt cleaner and more sustainable practices, aiming for a 25% reduction in emissions by 2030 and achieving Net Zero status by 2050.

📉 The volatility of international markets and the challenges brought by Brexit add further complexity, affecting the profitability and sustainability of the sector, which is crucially dependent on exports.

🌱🚜 Looking to the future, the need for innovation and investment in green technologies is more urgent than ever. In this regard, investing in precision agriculture and regenerative farming practices is vital, as they offer the necessary tools to face these environmental and market challenges.

🤝 Collaboration between governments, research institutes, and farmers will be crucial in adapting the sector to new demands and ensuring that it continues to be a vital force for local economies in the coming years.

I invite everyone to reflect and share: How is sustainability being integrated into your farming practices? What innovations do you think can transform the sector? What insights do you have when comparing it to Brazilian agriculture?

Figure 13: Irish Ministry of Agriculture

Figure 14: High-level discussions at the Irish Ministry of Agriculture

Figure 15: On top of a (very cold) hill!

Figure 16: The “gang” in an amazing Irish castle. These moments will be forever at my heart and mind. Thanks a lot, Nuffield.