

The Economy of Decarbonization: An Assessment of the Economic Benefits of Carbon Credits in Renewable Energy

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Abstract: The decarbonization of the economy has become a global imperative to address the challenges posed by climate change and to promote sustainable development. In this context, carbon credits emerge as one of the primary economic instruments for mitigating greenhouse gas (GHG) emissions and encouraging the transition to renewable energy sources. Beyond their environmental role, these credits present significant opportunities for economic growth, generating financial benefits for investors, companies, and governments. This article examines how carbon credits contribute to the development of a sustainable economy, with a particular focus on the renewable energy sector, highlighting their relevance as mechanisms to align environmental and economic objectives. The present study was conducted through an in-depth qualitative approach, which is fundamental for evaluating the economic benefits of carbon credits in the renewable energy context in Brazil. The primary objective of this scientific article is to analyze the economic benefits associated with carbon credits within the renewable energy sector, emphasizing how these benefits impact investors, companies, and governments, as well as their role in fostering a low-carbon economy. In summary, this article demonstrated that carbon credits play a central role in the transition to a low-carbon economy, promoting economic and environmental benefits that positively affect governments, businesses, and investors. The analysis underscored that these instruments are indispensable for advancing sustainable economic growth.

Keywords: Decarbonization of the economy; Economic instruments; Carbon credits; Renewable energy.

Date of Submission: 17-01-2025

Date of acceptance: 31-01-2025

I. INTRODUCTION

The intensification of climate change has driven governments, companies, and international organizations to seek solutions to reduce greenhouse gas (GHG) emissions and accelerate the transition to a low-carbon economy. In this context, carbon credits have gained prominence as an effective tool for pricing emissions, promoting the use of renewable energy sources, and stimulating technological innovations across various sectors.

These credits not only provide a practical approach to environmental mitigation but also create new investment and economic growth opportunities, establishing themselves as a central component of sustainable development strategies at the global level. Brazil, with its vast wealth of natural resources and significant potential for renewable energy, plays a strategic role in the implementation of carbon credits. Programs such as *RenovaBio* and initiatives focused on sustainable agriculture have demonstrated the positive impact of these mechanisms in key sectors of the economy.

Silva (2024) highlights Brazil as one of the countries with a robust regulatory framework, excelling in the issuance of carbon credits, fostering renewable energy incentives, and mitigating greenhouse gas emissions. This article aims to explore the economic benefits of carbon credits in the context of renewable energy, analyzing how they promote a balance between economic growth and environmental sustainability while strengthening the foundations for a resilient and inclusive economy.

The study was conducted using an in-depth qualitative approach, which is essential for evaluating the economic benefits of carbon credits in Brazil's renewable energy sector. The primary objective of this scientific article is to analyze the economic benefits associated with carbon credits in the context of renewable energy, highlighting how these benefits impact investors, companies, and governments, as well as their role in promoting a low-carbon economy.

The specific objectives are as follows: To investigate how carbon credits have driven the adoption of renewable energy sources in global and regional markets, fostering the transition to a sustainable energy matrix. To evaluate the economic gains generated by the commercialization of carbon credits for investors and ventures related to renewable energy. To examine how carbon credits contribute to balancing environmental sustainability and economic growth in the development of renewable energy projects.

To provide a structured and detailed analysis, this article is organized into four main sections. Section 1 - Introduction presents the general context of the study, addressing the importance of carbon credits in combating climate change and promoting renewable energy, along with the research objectives. Section 2 - Materials and Methods describes the methodological approach adopted, including data analysis, literature review, and the criteria used to explore the economic impacts of carbon credits. Section 3 - Theoretical Framework discusses key concepts related to the topic, focusing on the role of carbon credits in the energy transition, their economic impacts, and their contribution to sustainability and economic growth. Finally, Section 4 - Conclusion synthesizes the study's main findings, evaluates the achievement of the proposed objectives, and highlights practical and theoretical implications, while suggesting avenues for future research. This organization facilitates a comprehensive understanding of the topic and offers an integrated perspective on the economic benefits of carbon credits in renewable energy.

II. EXPERIMENTAL PROCEDURE

The present study was conducted using an in-depth qualitative approach, which proved fundamental for evaluating the economic benefits of carbon credits in renewable energy in Brazil. This methodological choice was based on the intention to deepen the understanding of the complexities and meanings associated with the experiences of various economic sectors in Brazil. The qualitative approach aimed to broaden the comprehension of the information obtained through the research procedures developed herein, allowing for a more integrated and comprehensive analysis of the realities experienced by Brazilian business organizations involved in this topic (Idelbrando, 2019).

The research procedures employed in this study were as follows: The investigation was conducted through a bibliographic review and the analysis of secondary data, both qualitative and quantitative, derived from official national and international documents. The bibliographic review aimed to provide a solid theoretical foundation for the study by exploring key academic discussions relevant to the topics addressed. This literature review served as an essential basis for the theoretical framework, enabling a critical analysis of the economic policies employed by Brazil and other countries to maximize the resources derived from the carbon credit market.

Additionally, the investigation of secondary data from official documents containing relevant information about the topic allowed for an in-depth understanding of the actions implemented and their outcomes in the aforementioned market. This analysis focused on quantitative variables (Figure 1) that can demonstrate the effectiveness of these actions (Grazziotin, Klaus, & Pereira, 2022).

This methodological focus facilitated a broader and more contextualized analysis of the collected data (Idelbrando, 2019). The analysis of the collected data was conducted by converging information from the bibliographic review and official documents (national and international).

The convergence of data enabled the verification of consistency and alignment among the different data sources, thus ensuring the validity and robustness of the conclusions drawn. The comparative analysis of qualitative and quantitative data contributed to clarifying the relationships between the implemented actions and the observed outcomes (both present and future) in the research (Grazziotin, Klaus, & Pereira, 2022).

III. THEORETICAL FRAMEWORK

3.1 The Role of Carbon Credits in the Energy Transition

Carbon credits play a fundamental role in the energy transition by encouraging the adoption of renewable energy sources in global and regional markets. By assigning economic value to the reduction of CO₂ emissions, these credits make clean energy projects more attractive to investors and companies. In Brazil, for instance, the replacement of non-renewable energy sources with renewable ones, such as wind and solar energy, contributes to the generation of carbon credits, driving the green economy (Salina, Almeida, & Bittencourt, 2018; Wills et al., 2022).

Silva (2024) highlights that fiscal incentives, a comprehensive regulatory framework, and additional benefits of the energy transition—such as sustainable economic practices and the adoption of clean technologies—bring new opportunities for innovation. Furthermore, the joint improvement and interaction between legislation, society, and the environment can help achieve greenhouse gas (GHG) emission reduction targets and other air pollutant reductions, positioning Brazil as a leader in the fight against climate change and in the issuance of carbon credits. T

The 2023–2025 Triennial Work Plan of the Ministry of Mines and Energy emphasized the potential of hydrogen in Brazil's carbon credit market by proposing discussions on the inclusion of the hydrogen supply chain in projects within voluntary and regulated markets. It also assessed the potential for credit generation, thereby fostering investments across various technological domains (Brazil, 2023).

The implementation of carbon credits has led to a significant expansion of renewable energy. In 2023, the capacity of renewable energy added to energy systems worldwide grew by 50%, reaching nearly 510 gigawatts (GW), with solar photovoltaic energy accounting for 75% of global additions (Clemente & Almeida, 2023; Hein, 2024).

This trend reflects the positive impact of carbon credits on the economic feasibility of sustainable projects. Moreover, carbon credits have encouraged investments in emerging technologies, such as green hydrogen. In Brazil, hydrogen production from renewable sources is seen as a way to store surplus energy, contributing to the stability of the energy matrix and emission reductions (Schneiders et al., 2023). Below, Table 1 presents the main benefits of carbon credits in the energy transition:

Table 1 - Benefits of Carbon Credits in the Energy Transition

Benefit	Description
Financial Incentives	Carbon credits provide economic returns for renewable energy projects, making them more competitive compared to fossil fuel-based sources.
Attraction of Investments	The ability to trade carbon credits attracts investors interested in sustainable and innovative projects.
Promotion of Clean Technologies	Encourages the development and adoption of low-carbon technologies, such as green hydrogen and advanced energy storage systems.
Contribution to Climate Goals	Assists countries and companies in meeting emission reduction commitments, aligning with the objectives of the Paris Agreement.
Sustainable Economic Development	Boosts the creation of green jobs and economic growth in sectors linked to renewable energy and environmental sustainability.

Source: Schneiders et al. (2023).

Carbon credits are market instruments that play a crucial role in the global energy transition. By promoting the use of renewable energy sources, they foster technological innovation and sustainable economic development. According to a report by the International Renewable Energy Agency (IRENA), the implementation of carbon pricing mechanisms, such as carbon credits, has accelerated investments in renewable energy in emerging countries, significantly contributing to the reduction of global CO₂ emissions (IRENA, 2023).

Furthermore, studies conducted by the World Economic Forum (WEF) highlight that the commercialization of carbon credits has attracted investors interested in low-carbon technologies, such as green hydrogen, whose applications are rapidly expanding in industrial and transportation sectors. This trend has also driven the creation of green jobs, particularly in regions with substantial renewable energy potential, such as Latin America and Africa (Brende & Sternfels, 2023).

Brazil, for instance, holds highly favorable conditions for developing a voluntary carbon credit market due to its potential demand (90–220 MtCO₂ eq by 2030) and its significant potential for carbon credit generation: 15% of the world's total carbon offset potential through natural climate solutions present within the country (McKinsey, 2022).

Another relevant aspect is the role of carbon credits in fulfilling global climate commitments. According to the Climate Action Tracker, countries that employ these market mechanisms are more aligned with the goals of the Paris Agreement, underscoring the importance of carbon credits in the realization of effective climate policies. These credits not only promote environmental sustainability but also strengthen local economies by reducing dependence on fossil fuels and enhancing energy resilience (CAT, 2024).

A close collaboration between governmental initiatives and private sector actions is essential to achieving the transition to new energy sources. Governments provide guidelines, incentives, and regulations that promote clean energy, discourage fossil fuels, and encourage innovation and investment in sustainable technologies (Song, Li, & Feng, 2024).

Silva (2024) highlights a disconnect between public decarbonization policies and social practices. For example, while Brazil's Vehicle Air Pollution Control Program (PROCONVE) and the National Policy on Climate Change (PNMC) establish clear directives for GHG emissions reduction, civil society organizations and distinct federative entities lack efficiency targets and integrated efforts within these public policies. This limitation is attributed to insufficient monitoring and evaluation mechanisms. Silva (2024) proposes the involvement of diverse stakeholders in a collaborative effort, leveraging the quintuple helix of innovation (Government, Industry, Academia, Society, and Environment) to ensure the implementation of these and new standards that can yield economic and environmental benefits for all sectors of society.

Thus, by providing economic and environmental benefits, carbon credits serve as a bridge to sustainable economic growth aligned with the climate and social demands of the 21st century. Their positive impact spans from mitigating climate change to energizing emerging economies, positioning them as an indispensable tool in advancing a low-carbon economy.

3.2 Economic Impacts of Carbon Credits on Renewable Energy Projects

Carbon credits have played a crucial role in financing renewable energy projects by providing economic incentives for reducing greenhouse gas (GHG) emissions. These credits enable projects, such as wind and solar farms, to generate additional revenue by selling their emission reductions to companies or countries that need to offset their excess emissions. According to the Carbon Market Report by the World Bank Group (2023), the increasing valuation of the global carbon credit market has positioned this instrument as a significant source of funding for the energy transition.

Table 2 – Economic Aspects vs. Impacts of Carbon Credits

Aspects	Economic Impacts
Reduction of Capital Costs	Facilitates access to financing and reduces financial risks associated with projects.
Asset Valuation	Increases project value due to the generation of recurring revenues.
Market Competitiveness	Provides advantages for sustainable projects compared to fossil fuel sources.
Contribution to Development	Stimulates investments in regions with low economic development.

Source: Mehrotra; Benjamin, 2022; WBG, 2023

In addition to facilitating financing, carbon credits enhance the economic competitiveness of renewable energy compared to fossil fuels. The additional costs associated with fossil fuels, internalized through policies such as carbon pricing, encourage industries to transition to clean energy sources. Studies by the International

Renewable Energy Agency (IRENA) (2022) highlight that projects certified for carbon credits attract more investors, particularly in emerging markets where renewable energy has significant growth potential.

In the research by Campello et al. (2014), the authors elucidate that instruments such as carbon credits also improve the economic feasibility of low-emission energy sources. Their study includes a technical and economic feasibility analysis of hybrid generation using municipal solid waste (MSW) and photovoltaic energy to serve small municipalities in Brazil, considering the commercialization of carbon credits with economic indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback.

However, Silva (2024) warns in her article that more efficient decarbonization strategies, involving integrated and collaborative public policies, must align with Brazil's international commitments. The lack of greenhouse gas (GHG) emissions data, due to inadequate monitoring and evaluation systems, hinders not only climate actions but also local, national, and international economies, as opportunities linked to the Paris Agreement are lost.

Cavalcante (2024) argues that data from the Environmental-Economic Accounts for Energy (SCEA) system can assist in estimating the carbon footprint. For this to be effective, it must integrate with energy generation/consumption systems in key sectors. The SCEA is capable of conducting simulations, identifying patterns of best practices and outcomes, proposing alternative GHG use solutions, increasing carbon stocks, and reducing GHG emissions. By aiming to mitigate GHG emissions, the SCEA can contribute to achieving a positive net balance and converting renewable energy production into carbon credits.

Finally, carbon credits contribute to local economic development, as renewable energy projects are often implemented in remote or underdeveloped areas. These projects create jobs, promote technology transfer, and boost local economies.

According to the Gold Standard Foundation, approximately 80% of projects certified for carbon credits in developing countries generate additional social benefits, such as energy access and community education, alongside their direct environmental impacts. Moreover, the involvement of local communities in certified renewable projects reinforces social engagement and acceptance, amplifying the positive impacts both in the short and long term (Mehrotra & Benjamin, 2022; WBG, 2023).

3.3 Sustainability and Economic Growth: A Carbon Credit-Based Approach

The relationship between sustainability and economic growth remains one of the major challenges for modern economies. Carbon credits have emerged as a mechanism to align environmental and economic goals, encouraging the reduction of greenhouse gas (GHG) emissions while promoting sustainable investments. Recent studies indicate that carbon credit markets not only reduce environmental impacts but also create significant opportunities for economic growth through technological innovation and new sustainable business models (Rocha Júnior et al., 2024).

In Brazil, the RenovaBio program established the country's first operational carbon credit market, requiring fuel distributors to purchase decarbonization credits from biofuels to meet their decarbonization targets (Oliveira, 2022).

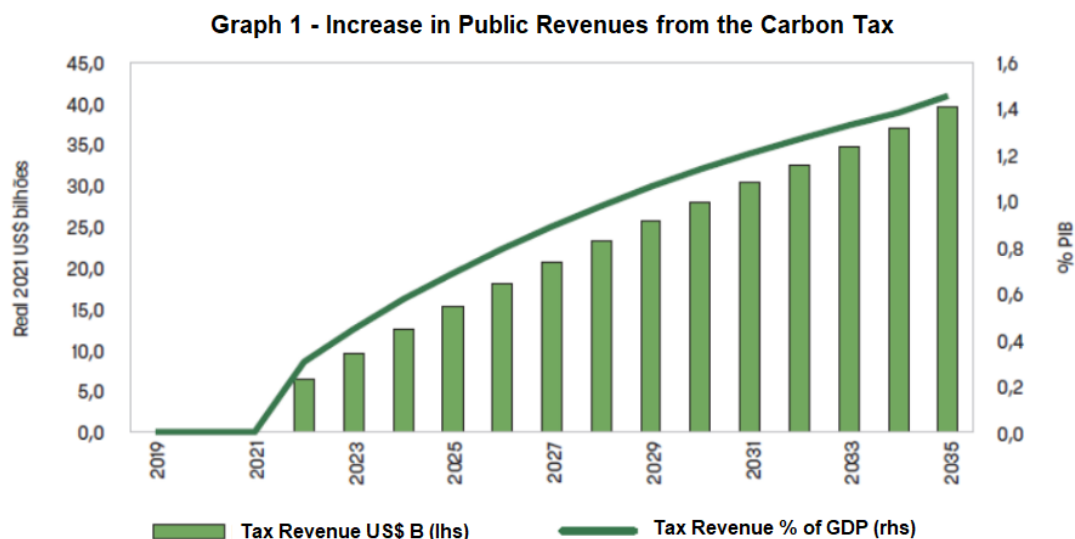
Moreover, the implementation of carbon credit projects has demonstrated significant potential to boost sectors such as renewable energy and low-carbon agriculture. According to Andrade and Rodrigues (2024), initiatives like RenovaBio and Sustainable Agriculture Programs have effectively combined environmental preservation with economic growth in rural areas.

These initiatives promote the inclusion of small and medium-sized enterprises, contributing to job creation and income generation in vulnerable regions. A relevant initiative to consider is the implementation of a comprehensive fiscal reform, including the adoption of a carbon tax. This measure aims to mitigate GHG emissions and enhance efficiency while transforming Brazil's tax system into a more productive and environmentally sustainable structure.

The implementation of a carbon tax could incentivize low-carbon activities while enabling fiscal reforms. Furthermore, this measure would simplify the tax system and serve as a potential revenue source for Brazil in the coming decade.

A simulation from the World Bank report indicates that introducing a carbon tax applicable to fossil fuels across all upstream economic activities—progressively increasing from R\$ 75 per ton of CO₂ (tCO₂) in early 2022 to R\$ 350 per tCO₂ in real terms by 2030—could generate additional revenue of approximately R\$ 140 billion. This amount would represent 1.2% of Brazil's Gross Domestic Product (GDP) in 2030, compared to maintaining the current tax regime.

See Graph 1 below:



Source: IEDI (2023)

The global carbon credit market has witnessed exponential growth and is projected to expand significantly in the coming decades. According to studies conducted by the international consultancy McKinsey, the value of carbon credits is expected to increase 15-fold or more by 2030 and up to 100-fold by 2050. McKinsey estimates that the global carbon credit market will grow from approximately USD 1 billion in 2021 to USD 50–100 billion by 2030 (McKinsey, 2022).

Beyond economic benefits, carbon credits strengthen international cooperation around the Sustainable Development Goals (SDGs), fostering a more balanced global economy. Studies show that developing countries can attract substantial international investments by participating in regulated or voluntary carbon markets (Silva, 2022).

Cavalcante (2024), in an article on carbon credit generation through the Environmental Economic Accounts System (SCEA), highlights the direct influence of GHG emissions on Brazil's SCEA. By reducing emissions to mitigate climate change impacts, promote resilience, and achieve a more sustainable economy, the SCEA positively affects the energy sector, economic costs, and carbon markets. Additionally, government policies are influenced by support mechanisms for generating carbon credits based on technologies and knowledge. The mitigation of GHG emissions promotes resource reuse, minimizes waste, and contributes to the overall carbon stock, fostering a circular economy.

This approach encourages the exchange of technology and knowledge, resulting in greater efficiency and competitiveness. Carbon credit markets also play a crucial role in advancing a circular economy, where resources are reused, and waste is minimized. By pricing carbon, businesses and governments are incentivized to adopt more sustainable practices, ensuring the efficient use of natural resources. According to Kruse (2023), integrating carbon credit systems into public policies can consolidate the transition to a more inclusive and resilient development model. Such mechanisms reinforce the synergy between economic growth and environmental sustainability, highlighting carbon credits as a vital tool for advancing global decarbonization efforts while promoting equitable economic development.

IV. CONCLUSION

This scientific article aimed to analyze the economic benefits associated with carbon credits in the context of renewable energy, highlighting their impacts on investors, businesses, and governments, as well as their role in promoting a low-carbon economy. To achieve this objective, three specific goals were defined, all of which were fully achieved throughout the study.

The research demonstrated how carbon credits have been instrumental in driving the transition to a cleaner and more sustainable energy matrix. The study revealed that these mechanisms promote the adoption of renewable sources by providing financial incentives for projects that prioritize the reduction of greenhouse gas (GHG) emissions. This context reinforces the strategic importance of carbon credits in mitigating climate change.

The study highlighted the economic gains derived from the commercialization of these credits, particularly regarding the financing of sustainable projects. It was observed that carbon credits not only attract investors but also provide greater economic viability to ventures in the renewable energy sector, fostering technological innovation and competitiveness in the global market.

The tables presented throughout the article complemented the theoretical discussions. Table 1 - Benefits of Carbon Credits in the Energy Transition highlighted the positive impacts of these instruments, such as emission reductions and the promotion of green jobs. Meanwhile, Table 2 - Aspects x Economic Impacts of Carbon Credits summarized the financial and structural effects of these mechanisms, demonstrating their ability to transform markets and promote a more resilient and sustainable economy.

The research also analyzed the relationship between environmental sustainability and economic growth. The graph presented in this subsection, Graph 1 - Increase in Public Revenues from the Carbon Tax, illustrated how carbon pricing can generate significant revenue for governments, which can be reinvested into sustainable development initiatives. This point underscores the relevance of carbon credits as an effective public policy instrument capable of aligning economic and environmental goals.

In summary, this article demonstrated that carbon credits play a central role in the transition to a low-carbon economy, promoting economic and environmental benefits that positively impact governments, businesses, and investors. The analysis emphasized that these instruments are indispensable for fostering sustainable economic growth.

For future research, it is suggested to deepen the analysis of the social impacts of carbon credits, exploring how these mechanisms can contribute to reducing regional inequalities and the inclusion of vulnerable communities in renewable energy projects.

Furthermore, it is recommended to investigate the effectiveness of voluntary carbon markets compared to regulated markets, in order to identify opportunities for improvement in both public and private policies related to the subject.

Conflict of interest

There is no conflict to disclose.

ACKNOWLEDGEMENT

The authors thank the Coordination of the MBA program in Renewable Energies, developed through the scientific partnership between the Euvaldo Lodi Institute and the Farias Brito University Center.

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