

Journal

The Capco Institute Journal of Financial Transformation

A new world order

Colliding worlds

Carbon credits and the energy sector in Brazil: energy transition, implicit carbon pricing, risk management and technological innovation

Livia Savignon

Journal

Recipient of the Apex Award for Publication Excellence

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2026, Edition 62

Journal

Welcome to the 62nd edition of the Capco Journal of Financial Transformation, the second to be published in partnership with King's College London, a world-renowned leader in education and research.

This year marks the Journal's 25th anniversary and the beginning of **Capco30**, our strategic vision as we build towards Capco's landmark 30th anniversary.

At the heart of Capco30 is The Expert Advantage: our commitment to be the trusted partner clients turn to when the stakes are highest. We are proud to have built an exceptional business by obsessing about our deep expertise, our strong client relationships, our innovative culture and our reputation for impact.

The Journal has embodied that ambition since its launch in 2001. Over the past quarter century, it has brought together leading academics and industry practitioners – including Nobel laureates, international regulators and board members of major institutions – to examine the forces shaping financial services and the wider global economy. We are equally proud to see Capco experts sharing their perspectives alongside such distinguished contributors.

As Professor Crawford Spence, our editor from King's College, observes in his introduction, this edition might aptly have been titled 'how to survive and thrive in turbulent times'.

After decades of globalization, firms are both refocusing on local market shifts and new forms of cross-border collaboration. Technology is driving integration as trade barriers rise; financial innovation is accelerating amid monetary realignment and volatile geopolitics; and the green transition is redrawing both energy markets and fiscal priorities.

Edition 62 focuses on the **new world order** emerging from these shifts – and how leaders across financial services and energy are rethinking established assumptions, navigating new risks and identifying opportunities for growth.

The coming decade could bring one of the most consequential reconfigurations of global business and economic systems in generations.

This environment reinforces the importance of expertise, judgement and the ability to turn insight into action. At Capco, we help clients connect vision models and strengthening resilience to reimagining customer experiences and the future of work.

We bring together industry depth, technology and data capabilities, and disciplined execution to help clients navigate the moments that matter most with confidence.

The Journal is one expression of that Expert Advantage: convening leading perspectives, challenging established thinking and helping shape the agendas that will define the future of our industries.

I hope you will find the articles in this edition both thought-provoking and valuable for informing your organization's future vision and strategic decisions.

My sincere thanks and appreciation to our contributors, readers and clients.



Annie- Marie Rowland

Annie Rowland, Capco CEO

2026, Edition 62

Editor's note



**KING'S
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We could equally have labelled this volume of the Journal of Financial Transformation 'how to survive and thrive in turbulent times', given that each of the articles effectively attempts to tackle this issue in their own unique way. Times are indeed turbulent. Recent months and years have borne witness to increased military conflict, heightened economic shocks and the emergence of new political forces.

These disruptions are often captured in popular discourse by reference to, variously, the decline of the rules based international order, the rise of authoritarianism and the re-emergence of nationalism and protectionism as challenges to globalization. While putting clear conceptual parameters around what is a very unsettled geopolitical period is difficult, there is at the very least little doubt that the world is changing and that a new order is emerging. To paraphrase an old political aphorism: the old is dying and the new is struggling to be born.

This geopolitical reshuffling is the backdrop to the current issue of the Journal. Contributors were asked to think about how financial services and energy might respond to, and indeed themselves help reshape, the new global order that is emerging. What they have presented here can be grouped into four conceptual clusters, each of which makes up a distinct sub-theme in this issue of the journal: colliding worlds; monetary risks; strategic pivots; and private markets.

The first group of articles we refer to here as colliding worlds. The worlds that collide here specifically are

those of finance and energy. Each of these forces us to zoom out from financial transactions and investments and think about the wider environmental and material basis for these. For example, Ragland's fascinating look at the arms race for computing power shows how the rapid expansion of data centers is at odds with the way in which existing energy infrastructure is built. Those who will be successful in rolling out advanced computing power are those who will be able to finance and build out alternative energy infrastructure at the same time.

This has strong parallels with Xu and Preda's article looking at the infrastructure of bitcoin mining, which demonstrates in some detail how supposedly digital assets have heavy materiality in terms of both the physical infrastructure that supports them and the energy consumption that goes into their mining and processing. Finally, Savignon takes the energy transition head on by exploring the mechanics and possibilities of carbon credits in Brazil, a country which is characterised by a dominance of renewables in its energy mix. Showing real heterogeneity in how carbon credits are deployed in different sectors in Brazil, this article concludes by outlining how those who are able to integrate thinking around finance, data and energy will be able benefit from and contribute to the energy transition in the Brazilian market.

Monetary risks refer to the various ways in which currencies are embroiled with risk at both the national and transnational levels. As the fundamental means via which deals are transacted, it is perhaps no surprise that we find money, in its various guises, to

have so many political inflections. Cryptoassets are often heralded as some kind of safe haven ('digital gold') during times of economic and political turmoil and there are many central banks across the globe who are now pursuing digital currency projects of their own. These have significantly lagged the development of private crypto initiatives. One of the reasons for this might be the perceived financial crime risk that is associated with digital currencies in general, something which Tjeransen's article outlines in detail.

Fiat currencies are also deeply imbricated in geopolitical factors. This is the subject of Hou et al's article which draws attention to the ways in which currency risk premia are associated with trade imbalances between nations. Such factors are of increasing importance to, not only forex traders, but any organization engaging in currency hedging. Finally, nowhere is the importance of currency to geopolitics more evident than in Zayim's article looking at how central banks engage in currency swaps with other central banks. Focusing on both China and the US, Zayim shows how each has sought to build up spheres of influence with different counterparties as part of larger attempts to accrue power and minimize geopolitical risk for themselves.

Our third conceptual 'bucket' looks at how individual organizations respond to geopolitical shifts. In other words, these articles look at the various strategic pivots that organizations make in order to survive and thrive in turbulent times. These strategic pivots can take different forms depending on the geography and industry in question. For example, Schnyder shows how banks in East Central Europe can mitigate risk in response to rising anti-FDI policies in that region. In Scriven's article the author shows how software delivery needs to be reconfigured in order to overcome increasing regulatory divergence and export controls.

In times of geopolitical uncertainty, capital markets can become less efficient in allocating capital and so firms have to focus more on their internal

efficiencies, which is what Gkikopoulos and Stathopoulos illustrate in their article exploring the relationship between firms and banks; such relationships have implications for tax planning and productivity. Political turbulence also impacts hiring strategies, which Nguyen and Sila demonstrate in relation to corporate hiring practices during times of election uncertainty. Finally, Confalone makes a strong case for a strategic pivot towards developing 'enterprise intelligence' in the age of AI, a shift which has governance implications for financial services organizations.

The final sub-theme of the issue reflects an ongoing interest that we have had in private markets. The shift from public to private markets is one of the big secular shifts of modern finance, which was dealt with explicitly in issue 61. In this issue, we build on this with two further articles. One of these, by Phalippou, tackles the shift of private equity towards retail investors, outlining the potential risks in selling private equity products that were designed with institutional investors in mind to a less informed and less powerful constituency. Preda and Chen's article pursues another tack, showing how venture capital funding in Asia and elsewhere has to be cognisant of surrounding government policy imperatives if it is to be successful.

Taken together, these articles argue that financial services are not simply being buffeted by geopolitical change. They are becoming one of the arenas in which that change is negotiated. Through payment systems, liquidity backstops, energy and computing infrastructure, corporate strategy and the evolving boundary between public and private markets, we can see how geopolitical forces manifest themselves and adapt to existing institutional constraints and imperatives.



Professor Crawford Spence
King's College London

Carbon credits and the energy sector in Brazil:

energy transition, implicit carbon pricing, risk management and technological innovation

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Abstract

The global energy transition constitutes one of the greatest structural challenges faced by the energy sector in the 21st century. The need to reduce greenhouse gas emissions, in line with international climate goals, imposes increasing restrictions on energy production, conversion, and consumption, without compromising security of supply, economic competitiveness, and the stability of energy systems. In this context, carbon credits emerge as a complementary economic instrument, capable of enabling gradual decarbonization trajectories, internalizing environmental externalities, and directing capital towards low-carbon solutions. In Brazil, a country characterized by a predominantly renewable electricity matrix, the relevance of the oil and gas sector, and a leading position in biofuels, carbon credits assume a unique strategic role. This article analyzes, from an academic and sectoral perspective, the relationship between energy transition and carbon credits in the Brazilian energy sector, discussing economic fundamentals, market architecture, sectoral applications, financial implications, integrity and governance challenges, as well as technological and innovation trends that shape the evolution of this market. The study argues that carbon markets are not merely complementary instruments to decarbonization, but increasingly strategic mechanisms capable of influencing investment allocation, competitiveness, and long-term energy planning. By examining regulatory developments, market dynamics, and technological enablers, the article concludes that the consolidation of a credible, transparent, and technologically robust carbon market will be essential for aligning Brazil's energy transition with economic resilience and global climate commitments.

1. Energy transition: global context and structural challenges

The contemporary energy transition differs from previous historical processes in that it is driven by global environmental constraints and not just by technological factors or resource scarcity.

The consolidation of scientific consensus on anthropogenic climate change, as summarized in the reports of the Intergovernmental Panel on Climate Change [IPCC (2023)] has established clear targets for reducing greenhouse gas emissions as a necessary condition for limiting global warming.

In this scenario, the energy sector occupies a central position. According to the International Energy Agency, the global energy system accounts for the largest share of CO₂ emissions, either directly, through the combustion of fossil fuels, or indirectly, through the electrification of still carbon-intensive end sectors [IEA (2021)]. At the same time, the energy sector itself is the main technological driver of the transition, enabling renewable sources, energy efficiency, electrification, and carbon capture and removal solutions.

The complexity of this process stems from the fact that energy systems are critical infrastructures, with long-lived assets, high capital costs, and strong interdependence with economic activity. Therefore, the energy transition cannot occur abruptly, at the risk of compromising security of supply, industrial competitiveness, and macroeconomic stability.

2. Carbon credits as an economic instrument for the energy transition

In this context of environmental constraints and economic imperatives, carbon credits emerge as an economic instrument for transition. Based on the principles of environmental economics, these instruments allow for the internalization of negative externalities associated with greenhouse gas emissions, assigning monetary value to their reduction or removal [OECD (2022)].

A carbon credit essentially represents the certified reduction of one ton of carbon dioxide equivalent (tCO₂e) relative to a methodologically defined baseline. Its economic function is not to replace structural decarbonization policies, but to reduce the aggregate cost of the transition, allowing reductions to occur where they are most economically efficient [World Bank (2024)].

For the energy sector, this logic is particularly relevant. Different segments, such as electricity generation, refining, oil and gas production, and bioenergy, have quite distinct marginal costs of emission abatement. Carbon credits allow these differences to be exploited, creating intersectoral and intertemporal flexibility in the decarbonization trajectory.

3. Marginal abatement costs: empirical evidence and observed data

The theoretical analysis of marginal costs of emissions abatement can be strengthened by observing consolidated empirical data. Recent World Bank reports indicate that the cost of emissions reduction varies significantly between technologies and sectors, reinforcing the economic rationale of carbon markets as instruments of allocative efficiency [World Bank (2024)].

According to the State and Trends of Carbon Pricing [World Bank (2024)], energy efficiency measures and operational emissions reductions in the energy sector have average costs of less than U.S.\$20/tCO₂e, while renewable generation projects generally range between U.S.\$30 and U.S.\$60/tCO₂e, depending on the regulatory context and the degree of technological maturity. In contrast, carbon removal technologies, such as direct air capture (DAC), still have high costs, often exceeding U.S.\$300/tCO₂e [World Bank (2024)].

This empirical evidence reinforces the logic that carbon credits allow for prioritizing lower-cost reductions in the short and medium term, while more capital-intensive technologies mature and reduce their learning curves, an aspect that is particularly relevant in the energy sector.

4. Architecture of carbon markets: regulated and voluntary

4.1 Regulated markets: evidence from the North Sea

The North Sea experience offers a concrete example of the application of regulated carbon markets and their interaction with carbon capture and storage (CCS) technologies. Countries such as Norway and the United Kingdom have developed CCS projects integrated with carbon pricing policies, creating clear economic incentives for mitigating industrial and energy emissions. Projects such as Northern Lights and Net Zero Teesside demonstrate how the existence of a stable regulatory framework, combined with explicit carbon prices, enables long-term investments in CCS, even in the face of relatively high marginal costs [IEA (2021)]. In these cases, carbon credits or permits act as a mechanism for internalizing environmental costs, making projects economically viable that would be unfeasible in an environment without pricing.

4.2 RenovaBio as a Brazilian case study of a hybrid market

In the Brazilian context, the RenovaBio program constitutes a relevant example of a hybrid instrument that combines elements of regulatory policy, a carbon credit market, and economic incentives. Although not a carbon market *stricto sensu*, RenovaBio establishes mandatory decarbonization targets for fuel distributors and creates decarbonization credits (CBIOs), which are traded on the market. RenovaBio demonstrates, in practice, how market mechanisms can be used to internalize environmental externalities in the energy sector, valuing the low-carbon attributes of biofuel production [MME (2023)]. The underlying economic logic is analogous to that of carbon credits: agents with lower abatement costs generate credits, while those with higher costs

acquire them to meet their targets. This Brazilian case exemplifies the strategic use of market instruments to enable the energy transition in specific sectors.

These experiences demonstrate that different institutional architectures can coexist, provided they are aligned with criteria of environmental integrity, regulatory predictability, and economic efficiency.

5. Sectoral applications of carbon credits in the energy sector

The use of carbon credits in the energy sector is heterogeneous, reflecting the structural, technological, and regulatory differences between its segments. Oil and gas, electricity generation, and bioenergy face distinct challenges in the energy transition, which influences the role played by credits as complementary economic instruments.

5.1 Oil and gas: carbon credits as a transition bridge

The oil and gas sector faces structural challenges in the energy transition. Although it remains essential for global energy security, it is an inherently emissive segment. In Brazil, however, offshore production has a lower carbon intensity than the international average, due to technological gains and operational efficiency, especially in the pre-salt layer [IEA (2021)].

Even so, regulatory, financial, and reputational pressures demand clear mitigation strategies. In this context, carbon credits play a bridging role in the transition, being used to offset residual emissions, enable flaring reduction projects, mitigate methane leaks, electrify platforms, and, in some cases, capture and store carbon [Blaufelder et al. (2021)].

From an academic point of view, it is crucial to emphasize that the use of credits in the oil and gas sector should be understood as

complementary and transitory, not replacing the need for structural transformation of the energy portfolio over time [IPCC (2023)].

5.2 Electric sector: systemic reliability and strategic use of credits

Despite the high participation of renewable sources, the Brazilian electricity sector faces growing challenges related to the intermittency of sources and the expansion of demand. The need for firm power and operational flexibility maintains the relevance of thermal sources, especially natural gas, to ensure system stability [EPE (2023)].

In this context, carbon credits assume a complementary role by allowing the offsetting of emissions associated with thermal generation necessary for system reliability. In parallel, financial resources from the carbon market can be directed to low-carbon structuring projects, such as bioenergy, forest restoration, and energy storage technologies.

This approach contributes to an orderly energy transition, avoiding abrupt solutions that compromise security of supply or excessively increase systemic costs [World Bank (2024)].

5.3 Biofuels and bioenergy as structuring vectors of the Brazilian transition

Brazil holds a prominent global position in biofuels, such as ethanol, biodiesel, biogas, and bioelectricity. These sources have a high potential for reducing emissions when compared to conventional fossil fuels, especially when considered throughout their entire lifecycle [MME (2023)].

Carbon credits play a central role in the economic viability of these chains, monetizing climate benefits that are not fully captured by traditional energy prices. For the energy sector, this represents an opportunity for diversification,

strengthening national solutions, and reducing regulatory and commercial risks associated with carbon intensity [OECD (2022)].

Together, these segments demonstrate that the role of carbon credits in the energy sector is inherently heterogeneous, varying according to technological structure, emissions profile, and degree of regulatory maturity.

6. Carbon credits as a risk management and capital allocation tool

With the advancement of carbon pricing policies and climate disclosure requirements, carbon credits are becoming integrated into risk management strategies in the energy sector. They act as a hedge against regulatory uncertainties, reputational risks, and potential financial impacts arising from emissions-intensive assets.

Financial institutions are increasingly incorporating carbon metrics into credit risk assessment, cost of capital, and eligibility for sustainable financing instruments. In this context, the ability of energy companies to structure robust and transparent strategies for the use of carbon credits becomes a relevant competitive differentiator [World Bank (2024)].

7. Environmental integrity, MRV and institutional governance

The effectiveness of carbon credits fundamentally depends on their environmental integrity. Questions about additionality, permanence, double counting, and measurement represent significant risks to market credibility, especially in countries with large territorial extensions such as Brazil [IETA (2023)].

In the energy sector, where projects involve critical assets and systemic impacts, robust measurement, reporting, and verification (MRV) systems are an indispensable condition for

regulatory acceptance and investor confidence. The absence of adequate governance can compromise not only individual projects but the legitimacy of the market [Energy Transitions Commission (2023)].

8. Regulatory development and integration with public policies

The advancement of the regulatory debate on the carbon market in Brazil represents a fundamental step towards the consolidation of credits as a structuring instrument of the energy transition [MME (2023)].

In this context, the holding of COP 30 in Belém do Pará marks an institutional turning point, with the announcement of the creation of a carbon credit certifier led by BNDES. The initiative seeks to provide credibility, standardization and transparency to a market historically marked by methodological uncertainties.

BNDES's role as a certifying entity directly addresses the challenges of environmental integrity and MRV, by monitoring the entire credit cycle, from formulation to retirement, reducing greenwashing risks and attracting long-term international capital for restoration, bioenergy and nature-based solutions projects.

9. Case study: the ProFloresta+ program as a model for sectoral decarbonization

The materialization of the theoretical concepts of flexibility and allocative efficiency can be observed in the ProFloresta+ program, a joint initiative between BNDES and Petrobras. This program exemplifies how major players in the energy sector use the carbon market as a 'transition bridge,' allowing them to maintain investments in long-life assets while offsetting operational emissions through nature-based solutions.

9.1 Market scale and dynamics

The first call for proposals for ProFloresta+, which closed on January 9, 2026, demonstrated a market receptiveness that exceeded initial expectations, attracting 16 proposals for forest restoration projects in the Amazon. The immediate goal is the acquisition of 5 million carbon credits (where each credit represents one ton of CO₂e removed), distributed across five strategic contracts. In the long term, the program projects restoring up to 50,000 hectares of degraded areas, generating approximately 15 million credits, a volume equivalent to the annual emissions of approximately 8.94 million gasoline-powered vehicles.

9.2 Economic rationality and risk management

Petrobras' strategy in this call for proposals aligns with the logic of the lowest marginal cost of abatement, since the company will select projects that present the lowest total cost for the amount of credits contracted. In addition to financial efficiency, the initiative addresses reputational and financial risk management, improving the company's ESG metrics in the eyes of international investors. For applicants, the program offers security and economic viability through access to differentiated BNDES financing lines, such as those from the Climate Fund, specifically aimed at restoration with native species.

9.3 Environmental integrity and governance

A critical point highlighted in the project is environmental integrity. Submitted proposals undergo a rigorous technical evaluation that analyzes environmental quality and compliance with socio-environmental safeguards. This methodological rigor is essential to avoid the risk of greenwashing and ensure that the generated credits have liquidity and real value

in the voluntary market and the future regulated Brazilian market. With a potential investment of over R\$1.5 billion, ProFloresta+ not only fosters the bioeconomy in the Amazon, but also consolidates the use of carbon credits as part of the economic infrastructure of the energy transition in Brazil.

10. Structural limitations on the use of credits in the energy sector

Despite their relevance, carbon credits have clear limits. Their excessive use can delay investments in low-carbon structural technologies and prolong dependence on emitting assets. The academic literature converges in stating that credits should be used in a complementary, temporary way, aligned with scientific decarbonization trajectories [IPCC (2023)].

In the energy sector, this implies establishing clear criteria for use, transparency, and temporality, preventing credits from becoming permanent substitutes for the necessary structural transformations.

11. Regulatory development in Brazil: the Carbon Market Bill

The advancement of the regulatory debate on the carbon market in Brazil represents a fundamental step towards consolidating carbon credits as a structuring instrument for the energy transition. The Bill that establishes the Brazilian Emissions Trading System seeks to create a regulated framework, with the definition of covered sectors, reduction targets, and rules for monitoring, reporting, and verification [MME (2023)].

The connection between this regulatory development and the market architecture discussed in Section 4 is direct. The institutionalization of a regulated market tends to reduce uncertainties, raise environmental integrity standards, and expand the energy

sector's participation in compliance mechanisms. At the same time, the regulatory design will need to engage with existing instruments, such as RenovaBio, to avoid overlaps and economic distortions.

From an academic point of view, the central challenge lies in balancing environmental rigor and economic flexibility. An excessively rigid market can increase transition costs and compromise the competitiveness of the energy sector, while an excessively flexible market can compromise its credibility and climate effectiveness [World Bank (2024)].

12. Technologies, innovation and trends in the carbon and energy market

The future of the integration between carbon credits and the energy sector will be largely determined by the convergence of technological advances, regulatory evolution, and the sophistication of financial markets. Far from being merely environmental instruments, carbon credits are increasingly taking on the role of economic infrastructure for the energy transition, influencing investment decisions, asset planning, and long-term corporate strategies.

12.1 Digitalization, advanced MRV, and reduction of information asymmetries

The digitalization of measurement, reporting, and verification (MRV) systems represents one of the most relevant transformations in the contemporary carbon market. The combined use of remote sensing, artificial intelligence, geospatial modeling, and digital records allows the transition from ex-post and sample models to near-continuous monitoring systems, reducing operational costs and information asymmetries [Blaufelder et al. (2021)].

“ *The consolidation of the integration between carbon credits and the energy sector will depend on the convergence of technological innovation, regulatory enhancement and the increasing maturity of financial markets.*

In the energy sector, this evolution is particularly relevant, given the systemic nature of emissions and the high financial value associated with credits. Advanced digital MRV not only strengthens the environmental integrity of credits but also increases their liquidity by reducing the risks of double counting, methodological questions, and regulatory uncertainties. In this context, technology ceases to be merely an operational tool and begins to act as a market enabling condition.

12.2 Carbon removal technologies and redefining the role of the energy sector

The advancement of carbon removal technologies tends to structurally redefine the role of the energy sector in carbon markets. Solutions such as direct air capture (DAC), bioenergy with carbon capture and storage (BECCS), and carbon capture and storage applied to energy assets (CCS) broaden the scope of the sector, which goes from a mere mitigating agent to a potential net provider of removals [IPCC (2023)].

From an economic point of view, these technologies have high marginal costs at the current stage, but play a strategic role in the long term, especially in climate neutrality and negative emissions scenarios. For the energy sector, this implies a gradual repositioning, in which existing assets can be reconfigured as

deep decarbonization platforms, provided they are inserted into appropriate regulatory and pricing frameworks.

12.3 Integration between energy, data and finance: carbon as an economic asset

A central trend is the growing integration between energy, data, and finance markets, in which carbon credits are treated as strategic economic assets, incorporated into energy planning decisions, project valuation, and financial structuring. Financial institutions already incorporate carbon metrics in risk analyses, cost of capital, and eligibility for sustainable financing instruments [World Bank (2024)].

In this context, carbon credits cease to be merely a compensatory mechanism and begin to directly influence capital allocation, the attractiveness of energy projects, and the relative competitiveness between technologies. This integration reinforces the role of credits as a bridge between climate objectives and economic rationality, especially in capital-intensive sectors with long investment horizons.

12.4 Regulatory standardization, market convergence, and institutional legitimacy

The consolidation of carbon credits as a structuring instrument of the energy transition will depend on regulatory evolution and convergence between voluntary and regulated markets. There is a clear trend towards higher environmental integrity standards, with increasing demands for additionality, permanence, traceability, and transparency [IETA (2023)].

For the energy sector, this standardization is fundamental. Regulatory predictability reduces legal risks, increases investor confidence, and

enables the integration of credits into formal energy and climate policy instruments. At the same time, convergence between voluntary and regulated markets tends to redefine corporate strategies, requiring greater alignment between the use of credits, decarbonization targets, and long-term planning.

12.5 Systemic implications for the energy transition

Taken together, these trends indicate that carbon credits are likely to consolidate as the economic infrastructure of the energy transition, linking technology, regulation, and finance. In the energy sector, their future relevance will not only be associated with the volume of credits traded, but also with their ability to:

- reduce systemic decarbonization costs
- enable technologies that are not yet competitive
- mitigate regulatory and financial risks
- and align private decisions with long-term climate objectives.

Thus, innovation in the carbon market should not be interpreted as a peripheral phenomenon, but as a central element of the economic and institutional reorganization that underpins the contemporary energy transition.

12.6 Technological convergence and implications for conclusive analysis

The technological, institutional, and financial trends discussed in this section reinforce the idea that carbon credits are undergoing a conceptual transformation: from a peripheral offsetting instrument to a structural element of the economic architecture of the energy transition. The digitalization of MRV systems, the advancement of carbon removal technologies, and the increasing

integration between energy, data, and finance indicate that the economic value of carbon is now determined not only by traded volumes but also by criteria of integrity, traceability, and regulatory alignment.

In the energy sector, this convergence redefines the role of carbon credits throughout the entire decision-making cycle, from asset planning to financial structuring, from risk management to public policy formulation. At the same time, the distinction between transitory and structural uses of credits is widening, reinforcing the need for differentiated and temporally conditioned sectoral approaches.

In this way, the discussion on technologies and innovation does not end in itself but provides the analytical basis for understanding the limits, opportunities, and institutional constraints explored in the conclusion of this article. It is from this integrated perspective, technology, economics, and governance, that it becomes possible to critically evaluate the role of carbon credits in the Brazilian energy transition.

13. Conclusion

Carbon credits play a relevant economic and institutional role in the energy transition of the Brazilian energy sector, not as a substitute mechanism for structural decarbonization, but as a catalyst capable of reducing systemic costs, mitigating risks, and increasing the allocative efficiency of climate capital. In a sector characterized by long-lived assets, high capital intensity, and strong interdependence with security of supply, the existence of flexible mechanisms for implicit carbon pricing proves to be particularly strategic.

From an economic point of view, the heterogeneity observed in the marginal abatement costs, evidenced by empirical data from the World

Bank, reinforces the rationality of carbon markets as transition instruments. By allowing lower-cost reductions to be prioritized in the short and medium term, carbon credits enable gradual decarbonization trajectories, while creating economic space for the technological maturation of more capital-intensive solutions, such as CCS, BECCS, and direct removal technologies.

Sectoral analysis has shown that the role of carbon credits in the energy sector is inherently heterogeneous. In the oil and gas segment, credits operate predominantly as a technological and financial bridge, allowing for the mitigation of residual emissions while technical and economic constraints persist in the complete replacement of assets. In the electricity sector, they function as a mechanism complementary to systemic reliability, by mitigating emissions associated with thermal generation necessary for the stability of the energy matrix. In biofuels and bioenergy, credits take on a more structural character, monetizing environmental attributes and reinforcing Brazil's comparative advantages in the global energy transition.

From an institutional perspective, the effectiveness of carbon credits critically depends on high standards of environmental integrity, robust measurement, reporting and verification (MRV) systems, and predictable regulatory frameworks. Analysis of international experiences, such as CCS projects in the North Sea, and national experiences, such as RenovaBio, ProFloresta+, and the certification initiative led by BNDES in the context of COP 30, indicates that

institutional credibility is a necessary condition for carbon credits to assume a structuring role in the energy sector, avoiding greenwashing risks and increasing their acceptance by global investors.

In addition, the advancement of the regulatory debate in Brazil, with the proposal for a national emissions trading system, signals a gradual transition from a predominantly voluntary model to hybrid and potentially regulated arrangements. This movement tends to redefine the strategic role of carbon credits in energy planning, requiring careful coordination between market instruments, sectoral policies, and long-term climate objectives. The absence of this coordination may compromise the economic efficiency and environmental legitimacy of the system; on the other hand, its proper integration can transform the carbon market into a central component of Brazilian energy and industrial policy.

Finally, the results indicate that, for financial institutions, the future of carbon credits in the energy sector will be closely tied to technological advancement and the integration of energy, data, and finance. The digitalization of MRV systems, the application of artificial intelligence, the development of structured market platforms, and the consolidation of carbon removal technologies are likely to reshape risk pricing, asset valuation, and investment structuring. As a result, carbon credits should not be viewed merely as environmental instruments, but as an emerging asset class whose strategic relevance will depend on regulatory stability, technological credibility, and institutional robustness within the broader energy transition.

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