



REVIEW ARTICLE

TECHNOLOGY TRANSFER, INNOVATION INTERMEDIARIES AND CARBON MARKET GOVERNANCE: THE POTENTIAL ROLE OF TECHNOLOGY TRANSFER OFFICES (TTO) IN THE BRAZILIAN EMISSIONS TRADING SYSTEM

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ABSTRACT

The implementation of the Brazilian Emissions Trading System (SBCE) represents a significant milestone in the country's climate governance framework and may influence technological development in sectors subject to carbon regulation. However, the relationship between carbon markets and technology transfer remains insufficiently explored, particularly regarding the institutional mechanisms that support innovation and capability building. This study analyses how the literature addresses the role of Technology Transfer Offices (TTOs) as intermediaries of technology transfer within the context of the SBCE. An integrative literature review was conducted using academic publications, technical reports, and policy documents on carbon markets, eco-innovation, technology transfer, and innovation governance. The findings indicate that existing studies focus primarily on regulatory design and emissions reduction, while paying limited attention to the institutions responsible for transforming carbon pricing incentives into technological capabilities. Furthermore, TTOs are largely absent from discussions despite their strategic role in intellectual property management and university-industry collaboration. The study argues that the effectiveness of the SBCE will depend not only on carbon pricing mechanisms but also on the capacity of innovation-support institutions to facilitate technology transfer and strengthen domestic innovation capabilities. These findings contribute to debates on carbon market governance, eco-innovation, and green reindustrialisation in developing economies.

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INTRODUCTION

The transition towards a low-carbon economy is reshaping the relationship between environmental regulation, industrial competitiveness, and technological development. Over recent decades, climate governance has progressively shifted from traditional command-and-control approaches towards market-based instruments designed to internalise environmental externalities and create incentives for emissions reduction. Within this context, carbon pricing mechanisms, particularly emissions trading systems (ETSs), have emerged as central policy instruments capable of aligning economic decision-making with climate mitigation objectives. Despite their growing adoption worldwide, the contribution of carbon markets to technological development remains a matter of debate. While environmental economics literature suggests that carbon pricing can stimulate innovation by increasing the

relative cost of carbon-intensive activities, evidence indicates that price signals alone are insufficient to generate structural technological transformation. The effectiveness of carbon markets depends on the existence of complementary institutions capable of fostering knowledge creation, technology transfer, innovation diffusion, and capability building. Consequently, the relationship between carbon pricing and technological change should not be understood as automatic but rather as mediated by broader innovation ecosystems and institutional arrangements. This challenge is particularly relevant in developing economies. Although carbon markets may facilitate access to low-carbon technologies and encourage cleaner production practices, they can also reinforce technological dependence if domestic innovation capacities remain weak. In such contexts, climate policy raises a broader developmental question: whether

carbon pricing mechanisms will merely accelerate the adoption of externally generated technologies or contribute to the creation of endogenous technological capabilities capable of supporting long-term industrial transformation. The Brazilian case provides an especially important setting for examining this issue. The establishment of the Brazilian Emissions Trading System (SBCE) through Law No. 15,042/2024 represents a major institutional milestone in the country's climate policy framework. At the same time, international regulatory developments, particularly the European Union Carbon Border Adjustment Mechanism (CBAM), have increased pressure on Brazilian firms to reduce emissions and improve their environmental performance in increasingly decarbonised global value chains. Although discussions surrounding the SBCE have expanded considerably in recent years, they remain predominantly focused on regulatory design, emissions accounting, governance arrangements, and market operation. Comparatively little attention has been devoted to the institutional mechanisms through which carbon pricing may influence technological development and innovation dynamics. More specifically, the role of Technology Transfer Offices (TTO) remains largely absent from debates concerning the implementation of the Brazilian carbon market, despite their formal responsibilities regarding intellectual property management, technology transfer, licensing activities, and university–industry collaboration.

This omission reveals a broader disconnect between climate policy and innovation policy. Whereas the literature on carbon markets has primarily focused on emissions reduction and economic efficiency, studies on technology transfer and innovation governance have rarely considered how carbon pricing mechanisms may reshape the demand for technological solutions and create new opportunities for knowledge commercialisation. As a result, important questions remain unanswered regarding the institutional conditions required for carbon markets to contribute not only to decarbonisation but also to technological upgrading and green industrial development. This study is grounded in the argument that the developmental impact of the SBCE will depend not only on the effectiveness of its carbon pricing mechanisms but also on its capacity to stimulate technology transfer and strengthen domestic innovation capabilities. In this regard, TTOs may constitute strategic intermediaries capable of connecting scientific knowledge generated by universities and research institutions with the technological demands emerging from regulated sectors. Against this backdrop, the objective of this article is to analyse how the recent literature and technical documents address the role of TTOs as intermediaries of technology transfer in sectors potentially covered by the Brazilian Emissions Trading System, discussing the extent to which these organisations may contribute to strengthening domestic technological capabilities and supporting a low-carbon industrial transition. To address this objective, the study adopts an integrative literature review, combining academic publications and technical reports in order to identify convergences, divergences, and gaps in the emerging debate concerning the relationship between carbon market governance, technology transfer, and innovation institutions.

FRAMEWORK

Carbon Markets and Environmental Economics: The theoretical foundations of emissions trading systems are rooted

in environmental economics and the notion that environmental externalities can be internalised through market-based instruments. According to this perspective, greenhouse gas emissions constitute negative externalities whose social costs are not fully reflected in market prices. Carbon pricing mechanisms seek to correct this market failure by incorporating the cost of emissions into firms' economic decision-making processes (Stavins, 2003; Tietenberg, 2006). Cap-and-trade systems operationalise this principle by establishing an aggregate emissions limit and allowing regulated entities to trade emission allowances. Under ideal conditions, such mechanisms promote emissions reductions at the lowest overall cost while encouraging firms to identify more efficient abatement strategies. Beyond their allocative efficiency, carbon markets are increasingly viewed as instruments capable of influencing investment patterns and directing economic activity towards low-carbon pathways. However, environmental economics also recognises that price signals alone are not sufficient to guarantee structural technological transformation. The effectiveness of carbon pricing depends on institutional stability, regulatory credibility, and the existence of complementary policies capable of supporting innovation and technological change. Consequently, carbon markets should be understood not merely as environmental instruments but also as potential components of broader development and industrial transformation strategies.

Eco-Innovation and Green Industrial Transformation: The relationship between environmental regulation and technological change is explored extensively within the eco-innovation literature. Building upon the induced innovation hypothesis, scholars argue that environmental policies influence the direction and intensity of technological development by altering relative prices and creating incentives for firms to invest in cleaner technologies (Jaffe, Newell & Stavins, 2005; Popp, 2010). Eco-innovation encompasses the development and implementation of products, processes, organisational practices, and business models that reduce environmental impacts while maintaining or enhancing economic value creation (Kemp & Pearson, 2007). Within this framework, carbon markets can act as catalysts for technological transformation by increasing the relative attractiveness of low-carbon technologies and discouraging carbon-intensive production systems. Nevertheless, the distribution of eco-innovation capabilities remains highly uneven across countries. Developed economies tend to benefit from stronger research infrastructures, more sophisticated innovation systems, and greater capacity to capture value from environmental technological change. Developing countries often face the challenge of participating in low-carbon transitions without becoming dependent on imported technologies. Therefore, the developmental implications of carbon markets depend not only on their environmental effectiveness but also on their ability to stimulate domestic innovation capabilities and support green industrial transformation. This perspective aligns with contemporary debates on green reindustrialisation, which emphasise the need to combine climate policy, industrial policy, and innovation policy in order to generate both environmental and developmental benefits.

Technology Transfer and Intellectual Property: Technology transfer constitutes a critical mechanism through which knowledge and technological capabilities are

disseminated across organisations, sectors, and countries. The literature conceptualises technology transfer as a multidimensional process involving not only the movement of technologies themselves but also the transfer of skills, organisational routines, managerial practices, and innovation capabilities (Maskus&Okediji, 2010). In the context of low-carbon transitions, technology transfer assumes particular relevance because many of the technologies required for emissions reduction remain concentrated in a relatively small number of countries and firms. Consequently, the diffusion of environmentally sound technologies has become a central component of international climate governance, including the framework established under the Paris Agreement. Intellectual property rights occupy a complex position within this debate. On one hand, intellectual property protection encourages innovation by allowing inventors and firms to appropriate the returns generated by technological investments. On the other hand, excessive protection may create barriers to technology diffusion, particularly in developing countries with limited technological capabilities.

The challenge, therefore, lies in balancing incentives for innovation with mechanisms that facilitate knowledge dissemination and technological learning. In the context of carbon markets, this balance becomes increasingly important as firms seek access to technologies capable of reducing emissions while maintaining competitiveness in regulated environments.

Innovation Intermediaries and TTOs: The National Innovation Systems literature emphasises that innovation rarely occurs through isolated actors. Instead, technological development emerges from interactions among universities, firms, governments, research institutes, and intermediary organisations responsible for facilitating knowledge flows and collaborative learning processes. Innovation intermediaries perform a particularly important role in reducing informational asymmetries, facilitating cooperation, and supporting technology commercialisation. Among these actors, TTOs occupy a strategic position within the Brazilian innovation system. Established under the Innovation Law 10,973/2004 (Brasil, 2004) and subsequently strengthened by the Legal Framework for Science, Technology and Innovation, TTOs are responsible for managing intellectual property portfolios, supporting technology transfer activities, negotiating licensing agreements, and fostering university–industry collaboration. From a theoretical perspective, TTOs can be interpreted as institutional bridges connecting scientific knowledge generation with market demands. Their relevance becomes particularly significant in the context of regulated carbon markets, where industrial sectors face growing pressure to adopt low-carbon technologies and develop innovative solutions capable of reducing emissions. Despite their formal responsibilities, however, studies indicate that Brazilian TTOs exhibit heterogeneous levels of organisational maturity and technological management capabilities. This variability may limit their ability to act as effective intermediaries in emerging low-carbon innovation ecosystems.

Conceptual Framework: Drawing upon the preceding theoretical perspectives, this study proposes that the relationship between carbon market regulation and green industrial transformation is neither direct nor automatic. Instead, it is mediated by technology transfer mechanisms and innovation-support institutions.

The conceptual framework underpinning this research assumes that carbon pricing generates economic incentives for decarbonisation, which in turn create demand for eco-innovations and low-carbon technologies. The extent to which these incentives contribute to domestic technological development depends on the effectiveness of technology transfer processes and the capacity of intermediary organisations to facilitate knowledge flows between research institutions and productive sectors. Within this framework, TTOs function as strategic intermediaries capable of transforming scientific knowledge into technological assets, facilitating technology transfer, and strengthening domestic innovation capabilities. Consequently, the developmental impact of the Brazilian Emissions Trading System depends not only on its capacity to reduce emissions but also on its ability to articulate carbon pricing mechanisms with innovation policies, intellectual property management, and institutional arrangements that support technological learning and green reindustrialisation.

RESULTS AND DISCUSSION

Overview of the Mapping Process: The search strategy applied to the SciELO and ScienceDirect databases initially yielded 84 records, of which 80 were identified in SciELO and four in ScienceDirect. Following the removal of duplicates and the screening of titles and abstracts, only studies demonstrating a substantive relationship with regulated carbon markets and/or technology transfer and eco-innovation mechanisms were retained. Studies whose connection to the topic was merely tangential, as well as those focused exclusively on voluntary carbon markets without engagement with regulatory discussions, were excluded. At the end of the process, 11 articles met the eligibility criteria and underwent full-text analysis, complemented by technical reports produced by federal government agencies and business organisations, resulting in a final corpus of 14 studies included in the review. The synthesis of this body of literature reveals considerable heterogeneity in analytical approaches, empirical objects, and levels of institutional maturity. In developed economies, quantitative studies predominate, focusing on the effects of regulated carbon markets, particularly the European Union Emissions Trading System (EU ETS), on emissions, productivity, investment, and economic performance. These studies reinforce the proposition that carbon pricing instruments can, under certain institutional conditions, reconcile environmental objectives with economic competitiveness, simultaneously contributing to emissions reduction and productive modernisation.

By contrast, recent Brazilian scholarship exhibits a predominantly normative and prospective orientation. A substantial proportion of studies focus on regulatory models, governance alternatives, accounting issues related to carbon credits, and institutional design proposals for the Brazilian Emissions Trading System (SBCE). This distinction reveals an important asymmetry between core and peripheral economies. While the international literature has progressed towards ex post assessments of the actual impacts of carbon pricing instruments, the Brazilian debate remains concentrated on policy formulation and institutional construction. This configuration suggests that Brazil is currently situated at an intermediate stage of regulatory maturity, characterised by the development of the institutional foundations required for the

implementation of a regulated carbon market. Consequently, a significant gap remains in the empirical evidence capable of anticipating the effects of the SBCE on innovation, industrial competitiveness, and technology transfer. Put differently, the national debate has advanced further in defining market rules than in understanding the mechanisms through which the market may influence the country's technological dynamics.

An intensification in the production of business and governmental reports has also been observed since 2021, largely associated with discussions surrounding the implementation of a domestic regulated carbon market and the implications of the European Union's Carbon Border Adjustment Mechanism (CBAM). These documents converge in advocating regulatory stability, legal certainty, and participatory governance as essential conditions for the success of the SBCE, while simultaneously emphasising its potential to position Brazil within decarbonised global value chains and attract investments associated with the ecological transition. Nevertheless, when analysed collectively, the studies reveal that discussions surrounding the SBCE are more advanced at the regulatory level than in understanding the mechanisms responsible for building domestic technological capabilities. The literature provides valuable insights into the functioning of regulated carbon markets but offers limited evidence regarding how such instruments may be integrated with national innovation systems and the institutional arrangements responsible for generating, absorbing, and disseminating technological knowledge.

Identified Technology Transfer Mechanisms: Studies examining international experiences with regulated carbon markets suggest that carbon pricing instruments generate economic signals capable of stimulating investment in low-carbon technologies, modernisation of productive assets, and increased corporate expenditure on research and development. Although many of these studies do not explicitly employ the term "technology transfer", their findings provide evidence of concrete processes of technological diffusion through the adoption of more efficient equipment, upgrading of production processes, and strengthening of firms' innovative capacities.

A significant interpretation emerging from the review is that technology transfer associated with carbon markets predominantly takes the form of technological diffusion and absorption rather than autonomous knowledge generation. In international cases, capital stock renewal and the adoption of environmentally efficient technologies represent indirect technology transfer mechanisms that contribute to enhancing competitiveness while reducing the carbon intensity of productive activities. In many contexts, these processes are accompanied by increases in environmental patents, expanded investment in research and development, and structural shifts in sectoral investment patterns. This finding connects the debate on carbon markets with the literature on eco-innovation, green industrial policy, and national innovation systems, suggesting that carbon pricing may act as a catalyst for more sustainable technological trajectories. Within the Brazilian context, technology transfer mechanisms appear in a more fragmented manner. Studies related to voluntary carbon markets, REDD+, and forest-based projects primarily highlight project-based learning processes, the dissemination of sustainable management practices, the adoption of nature-based solutions, and the development of eco-innovations associated with the bioeconomy. However, these studies also point to challenges related to governance, benefit-sharing

arrangements, and the risk of reproducing socio-environmental asymmetries. In such cases, technology transfer tends to concentrate on monitoring technologies, certification systems, environmental management, and territorial governance tools, with comparatively less evidence of autonomous development of complex technologies or systematic strengthening of national innovation capabilities. This finding suggests that a substantial proportion of the observed processes involve the absorption and adaptation of already established technologies rather than the creation of endogenous technological trajectories. Policy-oriented documents concerning the future SBCE emphasise potential technology transfer mechanisms associated with the establishment of research and development funds financed through auction revenues, the strengthening of monitoring, reporting, and verification (MRV) infrastructure, and international technical cooperation. While relevant, these mechanisms remain largely programmatic, given the absence of sufficient empirical evidence to assess their effectiveness. The integrated analysis of the reviewed studies enabled the identification of four major categories of technology transfer mechanisms: (i) productive capital modernisation induced by carbon pricing; (ii) project-based learning and local diffusion of imported technologies; (iii) collaborative research and technological development financed by climate-related instruments; and (iv) the construction of institutional capabilities related to governance, MRV systems, and innovation management. An important contribution of this review is the observation that existing studies focus predominantly on mechanisms of technological absorption, devoting comparatively less attention to processes associated with the endogenous generation of innovative capabilities. This gap is particularly significant in the Brazilian context, where the challenge of the ecological transition is closely linked to the need for a knowledge- and innovation-based green reindustrialisation strategy.

Thematic Synthesis of Findings: The integrative review enabled the organisation of findings into three central analytical dimensions: (i) regulatory design and institutional capabilities; (ii) technology transfer and innovation mechanisms induced by carbon pricing; and (iii) challenges related to the development of domestic technological capabilities. The first dimension concerns the regulatory design of the SBCE and the institutional capabilities required for its implementation. The studies converge in advocating regulatory stability, participatory governance, and stronger integration between climate, industrial, and innovation policies. Within this body of literature, technology transfer is more frequently presented as a prerequisite for productive transition than as a clearly defined set of operational mechanisms. The second dimension encompasses evidence derived from international experiences. The findings indicate that regulated carbon markets, when combined with innovation policies and complementary financing instruments, can stimulate investment in low-carbon assets, increase environmental patenting activity, and accelerate industrial modernisation. Such evidence suggests that carbon markets may function as indirect technology transfer mechanisms, provided that they are accompanied by policies capable of strengthening local innovative capacities. The third dimension highlights the principal weaknesses identified in the Brazilian case. Although the country possesses substantial experience with voluntary carbon markets and forest-based projects, significant challenges remain regarding technological dependence, limited local appropriation of innovation benefits,

and the fragility of mechanisms aimed at building domestic technological capabilities. Within this context, one of the most significant findings of the review is the limited presence of TTOs in the literature on carbon markets. Given their responsibilities in intellectual property management, technology transfer, and university–industry collaboration, the absence of these actors suggests a disconnection between climate policy and innovation policy agendas. This gap may significantly constrain the ability of the SBCE to generate transformative effects on the national technological base. The combined analysis of the three dimensions suggests the existence of a causal chain in which regulatory design creates economic incentives for decarbonisation, while technology transfer mechanisms and institutional capability-building processes act as mediating factors between carbon pricing and eco-innovation outcomes. Accordingly, the effectiveness of the SBCE will depend not only on the robustness of its regulatory instruments but also on the capacity of the national innovation system to convert economic signals into concrete processes of technological learning and productive transformation. Finally, the findings enable the identification of three distinct levels of technology transfer within the reviewed literature: operational technology transfer, related to the adoption of equipment and production processes; organisational technology transfer, associated with managerial capabilities, certification systems, and environmental governance; and strategic technology transfer, linked to research and development, intellectual property, green patents, and university–industry collaboration. While the first two levels appear consistently throughout the reviewed studies, the third remains comparatively underexplored. This finding suggests that the principal challenge facing the SBCE is not merely the promotion of low-carbon technology adoption but the creation of institutional conditions that enable technology transfer to evolve from the simple absorption of external solutions towards the development of endogenous innovative capabilities. In this regard, Brazil's green reindustrialisation agenda will depend upon the effective integration of the regulated carbon market, innovation policies, and structured technology transfer mechanisms.

FINAL CONSIDERATIONS

This study examined how the literature and technical documents address the role of TTOs as technology transfer intermediaries within the context of the Brazilian Emissions Trading System (SBCE). The findings indicate that, although carbon pricing mechanisms are increasingly recognised as instruments capable of promoting emissions reductions and stimulating technological modernisation, the institutional mechanisms linking carbon market governance to technology transfer remain insufficiently explored, particularly in developing economies. The review demonstrates that international experiences with emissions trading systems have generated positive outcomes in terms of emissions reductions, investment in low-carbon technologies, and environmental innovation. However, these effects have largely been observed in countries with well-established innovation systems and strong technological capabilities. In the Brazilian context, discussions surrounding the SBCE have focused predominantly on regulatory design and market operation, while paying limited attention to the institutional arrangements required to transform carbon pricing incentives into domestic technological capabilities.

A central finding of this study is the limited presence of TTOs in the literature on carbon markets, despite their formal responsibilities regarding intellectual property management, technology transfer, licensing activities, and university–industry collaboration. This gap suggests a disconnect between climate policy and innovation policy, reducing the potential of the SBCE to contribute to broader processes of technological upgrading and green industrial transformation. From a theoretical perspective, the study contributes to bridging the literature on carbon markets, eco-innovation, technology transfer, and innovation intermediaries. The analysis suggests that the developmental impact of the SBCE will depend not only on the effectiveness of carbon pricing mechanisms but also on the capacity of innovation-support institutions to facilitate knowledge flows, technological learning, and collaborative innovation processes. From a policy perspective, the findings highlight the importance of strengthening the integration between the SBCE and the Brazilian innovation system. Greater involvement of TTOs and research institutions in technology transfer initiatives, collaborative research projects, and low-carbon innovation programmes may enhance the capacity of regulated sectors to respond to decarbonisation challenges while strengthening domestic technological capabilities. Finally, future research should investigate empirically how firms, research institutions, and TTOs interact within sectors covered by the SBCE. Such studies may provide valuable evidence regarding the institutional conditions under which carbon markets can contribute not only to emissions reduction but also to innovation, technological development, and green reindustrialisation in emerging economies.

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