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Transition to sustainable mobility through the lens of policy mixes: the experiences of Brazil and China

Transição para a mobilidade sustentável sob a ótica dos policy mixes: as experiências do Brasil e da China

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Abstract

The transition to sustainable mobility poses a major challenge for developing countries, as it requires the articulation of industrial, environmental, and innovation policies capable of promoting transport decarbonization and enhancing the competitiveness of the automotive industry. This article analyzes the policy instruments adopted to promote the transition to sustainable mobility in the automotive industries of emerging economies through the experiences of Brazil and China. The study adopts a qualitative approach grounded in the policy mix framework, which conceptualizes public policy as a combination of multiple policy instruments designed to achieve governmental objectives. The central research question is: How do interactions among policy instruments shape the technological trajectories of decarbonization in the automotive industry? Drawing on the experiences, the paper examines the phenomenon of policy layering, characterized by incremental institutional change in which new elements are added to pre-existing arrangements. Based on a content analysis of primary and secondary sources, the findings indicate that the Brazilian automotive policy adopts a technology-neutral policy mix, in which decarbonization may be achieved through multiple solutions that contribute to reducing greenhouse gas emissions, with electromobility representing one of the possible technological pathways. In China, the most recent configuration of automotive policy is built around a mission-oriented policy mix aimed at achieving global leadership in electromobility, in which vehicle electrification constitutes the dominant technological pathway for transport decarbonization.

Keywords: Automotive Industry; Emerging Economies; Decarbonization.

Resumo

A transição para a mobilidade sustentável representa um desafio significativo para países em desenvolvimento, uma vez que exige a articulação de políticas industriais, ambientais e de inovação capazes de promover a descarbonização do transporte e fortalecer a competitividade da indústria automotiva. Este artigo analisa os instrumentos de política pública adotados para promover a transição para a mobilidade sustentável nas indústrias automotivas de economias emergentes a partir das experiências do Brasil e da China. O estudo adota uma abordagem qualitativa fundamentada no referencial de *policy mix*, que concebe as políticas públicas como uma combinação de múltiplos instrumentos destinados ao alcance de objetivos governamentais. A questão central da pesquisa é: como as interações entre instrumentos políticos moldam as trajetórias tecnológicas da descarbonização da indústria automotiva? A partir das experiências, o artigo examina o fenômeno do *layering* político, caracterizado por mudanças institucionais incrementais nas quais novos elementos são adicionados a mecanismos preexistentes. Com base na análise de conteúdo de fontes primárias e secundárias, os resultados indicam que a política automotiva brasileira adota *policy mix* tecnologicamente neutro, em que a descarbonização pode ser alcançada por meio de

múltiplas soluções que contribuam para a redução das emissões de gases de efeito estufa, sendo a eletromobilidade uma das possíveis trajetórias tecnológicas. Na China, a configuração mais recente da política automotiva estrutura-se em torno de um *policy mix* orientado por missão, voltado à conquista da liderança global em eletromobilidade, no qual a eletrificação constitui a trajetória tecnológica dominante para a descarbonização do transporte.

Palavras-chave: Indústria Automotiva; Economias Emergentes; Descarbonização.

1 INTRODUCTION

The need to mitigate greenhouse gas (GHG) emissions has repositioned the automotive industry at the center of global decarbonization strategies due to its longstanding dependence on fossil fuels. This context has catalyzed a series of technological disruptions and fostered increasing integration among the automotive, energy, and information technology sectors (IEA, 2026).

International reports identify the automotive sector and road transportation as among the largest contributors to global greenhouse gas emissions. The International Energy Agency (IEA) estimates that road transport emitted more than 6 Gt of CO_2 in 2024, making it one of the world's largest sectoral sources of emissions. Likewise, the World Economic Forum (WEF) highlights that the automotive industry accounts for more than 10% of global industrial emissions when considering its extensive value chain and its intensive use of carbon-intensive materials (IEA, 2025; WEF, 2025).

Against this backdrop, the decarbonization of the automotive sector has become a central objective of global industrial policy, driven by the substantial contribution of transportation to greenhouse gas emissions. The transport sector accounts for approximately 20% to 27% of total CO_2 emissions worldwide and in the European Union, with passenger vehicles responsible for nearly half of this total (Rimpas et al., 2025; Zhang et al., 2023).

The establishment and consolidation of the automotive industry in emerging economies have been integral to industrialization strategies aimed at strengthening domestic component industries and enhancing global competitiveness. Beyond its economic importance, the sector serves as a driver of socioeconomic development by generating direct and indirect employment, fostering industrial clusters, and contributing significantly to gross domestic product (GDP) (Koziuk, 2022).

Although foreign direct investment (FDI) has been instrumental in the initial expansion of the automotive industry in countries such as Brazil, Mexico, China, and India, their integration into the global economy remains constrained by the structural and hierarchical characteristics of global value chains, in which emerging economies generally occupy peripheral positions within the international division of labor (Amighini; Gorgoni, 2014). Furthermore, infrastructure bottlenecks, shortages of skilled labor, competitive pressures, and environmental challenges continue to hinder sustainable growth, requiring mitigation measures and industrial strategies to ensure the sector's long-term competitiveness (Monye, 2023; Ikome; Laseinde; Katumba, 2022).

These conditions make the transition toward a decarbonized automotive industry particularly challenging for emerging economies. On the one hand, these countries must respond to the growing pressure to reduce emissions and adopt sustainable technologies. On the other, they must preserve productive capabilities, strengthen industrial competitiveness, and overcome structural constraints associated with their position in global value chains. The transition is therefore not solely a technological process, but also a policy challenge involving the coordination of multiple objectives, instruments, and institutional arrangements.

Against this background, this study is based on the premise that the transition toward decarbonization is a multidimensional process shaped by the configuration of multiple public policy instruments. This trajectory is reflected in the reconfiguration of automotive policy toward emission reduction through the deployment of different policy instruments designed to define and achieve governmental objectives (Bali et al., 2021). The policy mix concept provides an analytical framework for explaining how combinations of multiple policy objectives and instruments influence the state's capacity to promote transformative change (Flanagan; Uyarra; Laranja, 2011; Howlett; Rayner, 2007; Rogge; Reichardt, 2016; Rogge; Capano; Howlett, 2020).

From this perspective, the effectiveness of decarbonization policies depends not only on the adoption of individual instruments, but also on how different instruments interact, complement or conflict with one another over time. Such interactions may shape the technological trajectories available to firms and influence the capacity of emerging economies to reconcile domestic productive legacies with new technological and environmental demands.

The experiences of Brazil and China are particularly relevant in this regard, as both countries have developed significant automotive industries while adopting distinct policy trajectories toward technological upgrading and sustainable mobility.

Despite the growing literature on policy mixes and sustainability transitions, comparative analyses of emerging economies remain comparatively limited, particularly regarding how the interaction between policy instruments and pre-existing productive and institutional structures shapes technological trajectories in carbon-intensive industries. The comparison between Brazil and China is analytically relevant because both players combine significant automotive production capabilities, strong state involvement in industrial policy, and the challenge of reconciling industrial competitiveness with decarbonization, while differing substantially in their productive legacies, energy systems, institutional arrangements, and strategies for technological development. This contrast makes it possible to examine how similar policy objectives can be pursued through different configurations and sequences of instruments, and how these configurations interact with country-specific institutional and productive conditions.

The contribution of this study to the policy mix literature lies, therefore, in connecting the analysis of instrument interactions with the institutional and productive contexts in which policy mixes evolve. Rather than treating policy mixes as configurations whose effectiveness can be assessed independently of context, the study examines how processes such as layering, reorientation of policy objectives, and the interaction between substantive and procedural instruments contribute to shaping distinct technological trajectories. In this sense, the comparative analysis extends the policy mix perspective by highlighting the role of productive legacies and institutional configurations as conditioning factors in the evolution and effectiveness of policy mixes in emerging economies.

Based on this theoretical perspective, the study advances the following research hypothesis: In emerging economies, the effectiveness of policy mixes in promoting automotive decarbonization depends on the degree to which policy instruments are coordinated and adapted to domestic institutional and productive conditions; consequently, policy mixes characterized by greater coherence and complementarity among instruments are more likely to support technological trajectories consistent with long-term decarbonization objectives. This hypothesis

is examined comparatively through the Brazilian and Chinese cases, allowing the analysis to assess whether differences in the configuration and interaction of policy instruments are associated with distinct technological trajectories.

Accordingly, this article addresses the following research question: How do interactions among policy instruments shape the technological trajectories of automotive industry decarbonization in emerging economies? The primary objective of this study is to analyze how interactions among policy instruments shape the technological trajectories of decarbonization in the automotive industry, drawing on the experiences of Brazil and China.

To address this question, the study adopts a qualitative research approach grounded in the policy mix framework and examines the experiences of Brazil and China. Based on a content analysis of primary and secondary sources, the findings indicate that the effectiveness of automotive decarbonization in emerging economies depends on the ability of policy mixes to reconcile institutional arrangements and domestic productive legacies with long-term strategic choices.

2 THE POLICY MIX APPROACH

For decades, the public policy literature focused on identifying, classifying, and evaluating individual policy instruments, examining how mechanisms such as taxes, subsidies, regulations, and public investment influence actors' behavior and contribute to governmental objectives. Seminal contributions by Tinbergen (1952) and Hood (1986), emphasized the effectiveness of specific instruments, while Lascoumes and Le Galès (2007) later consolidated policy instruments as central analytical units for understanding state action and governance.

However, complex challenges such as transport decarbonization involve multiple actors, different levels of government, market failures, environmental externalities, technological uncertainty, and path dependence. Under these conditions, isolated policy instruments are unlikely to simultaneously overcome the economic, institutional, technological, and behavioral barriers that constrain sustainable innovation (Howlett; Rayner, 2007; Rogge; Reichardt, 2016; Capano; Howlett, 2020).

To address these limitations, the policy mix approach conceptualizes public policy as a dynamic configuration of objectives, strategies, and instruments that interact across time and

governance levels. Rather than evaluating individual instruments, this perspective focuses on the complementarities, synergies, and conflicts among policy components, recognizing that their overall configuration shapes policy effectiveness and the capacity to induce structural changes in socio-technical systems (Flanagan; Uyarra; Laranja, 2011; Howlett; Rayner, 2007; Capano; Howlett, 2020).

Building on this perspective, Rogge and Reichardt (2016) define a policy mix as the combination of policy elements (strategies, objectives, and instruments) together with key characteristics of the policy arrangement itself, including consistency, coherence, credibility, and comprehensiveness. Accordingly, policy mix analysis extends beyond the identification of individual instruments to examine their interactions, evolution over time, and coordination across governance levels, recognizing sustainability transitions as dynamic and multidimensional policy processes whose effectiveness depends on the interaction among multiple policy components.

Because policy mixes comprise different policy instruments, their analysis also requires understanding the distinct functions performed by each instrument and the mechanisms through which they influence decision-making and stakeholder behavior. In this regard, Hood's (1986) taxonomy, later refined by Howlett (2000, 2019), remains one of the most influential frameworks for classifying policy instruments according to the governmental resources they mobilize and the ways in which they shape society.

2.1 POLICY INSTRUMENTS

The literature recognizes that governments employ different policy instruments to influence social behavior and promote economic and institutional change. Hood's (1986) resource-based taxonomy, further developed by Howlett (2000, 2019) and synthesized by Bali et al. (2021), identifies four governmental resources that underpin policy instruments: information (nodality), authority, financial resources (treasure), and organizational capacity (organization).

Based on this framework, Howlett (2000) distinguishes between substantive and procedural policy instruments. Substantive instruments directly affect the production, distribution, and consumption of goods and services by altering economic incentives, regulatory

constraints, or technological conditions. In electric mobility, examples include EV purchase subsidies, tax incentives, public investment in charging infrastructure, mandatory energy-efficiency standards, vehicle emission limits, local-content requirements, and public procurement programs.

Procedural instruments influence policy outcomes indirectly by strengthening coordination, participation, information sharing, and institutional capacity among stakeholders. Examples include advisory councils, interministerial committees, technology observatories, data-sharing platforms, training programs, and cooperative arrangements across different levels of government. According to Howlett (2000), these instruments become increasingly important in contexts of high institutional complexity, where coordination among multiple actors is essential for effective policy implementation.

The combination of substantive and procedural instruments is particularly important in policies supporting the transition toward low-carbon, which involve multiple stakeholders, high uncertainty, and significant barriers to innovation. Bouma et al. (2018) argue that policy mixes emerge because sustainable transitions are constrained by the coexistence of different types of failures, including market failures, such as environmental externalities and information asymmetries, and behavioral failures associated with bounded rationality, risk aversion, and the persistence of established consumption patterns.

Accordingly, substantive and procedural instruments perform complementary roles. While the former modify economic and regulatory incentives directly, the latter enhance institutional coordination, policy learning, information exchange, and the capacities required for implementation. In electric mobility, behavioral barriers also matter, particularly factors such as range anxiety, perceived risk, and consumer uncertainty regarding electric vehicles (Rezvani; Jansson; Bodin, 2015). Combining different policy instruments can therefore strengthen governments' ability to address the multiple obstacles to sustainable mobility transitions in an integrated manner (Rogge; Reichardt, 2016).

2.2 COHERENCE, CONSISTENCY, AND LAYERING

A central contribution of policy mix literature is the recognition that policy effectiveness depends on the extent to which multiple instruments interact. Rogge and Reichardt (2016)

identify four characteristics that shape policy effectiveness: consistency, coherence, credibility, and comprehensiveness. Consistency refers to the compatibility among policy objectives and instruments, avoiding contradictions and conflicting incentives. Coherence concerns the systematic alignment between objectives, instruments, and policy processes, generating synergistic effects. Credibility reflects the stability and predictability of policies over time, while comprehensiveness denotes the extent to which the policy mix encompasses the instruments required to address complex challenges.

Subsequent studies argue that policy mixes characterized by greater consistency, coherence, and credibility reduce regulatory uncertainty, strengthen investor confidence, and stimulate innovation and sustainable technologies (Howlett; Rayner, 2007). Effective policy design therefore requires combinations of instruments that reinforce rather than undermine one another.

Nevertheless, policy mixes rarely emerge as fully designed systems. Instead, they typically evolve incrementally through successive reforms, institutional adaptation, and the addition of new policy instruments reflecting changing governmental priorities, state capacities, and technological conditions (Howlett; Rayner, 2007). This evolutionary process is captured by the concept of layering, developed by Mahoney and Thelen (2010), whereby new institutional rules are progressively added to existing arrangements without replacing them. Applied to policy mixes, layering refers to the accumulation of new policy instruments and objectives within existing regulatory frameworks, creating multiple institutional layers shaped by different historical contexts.

Layering can strengthen a policy mix when new instruments complement and update existing ones, increasing the system's capacity to address emerging challenges while preserving institutional continuity. However, poorly coordinated layers may generate regulatory overlap, conflicting rules, and greater institutional complexity. In this regard, Howlett and Rayner (2007) argue that policy mixes are often improved through patching incremental adjustments intended to reduce inconsistencies and enhance coherence without requiring comprehensive institutional reform. Examining the interactions, complementarities, and potential conflicts among policy instruments therefore constitutes one of the principal analytical contributions of the policy mix approach.

3 METHODOLOGY

The contributions of the policy mix literature makes it possible to examine the evolution of automotive policies, assessing whether successive policy mixes incorporated new objectives related to innovation, international competitiveness, and transport decarbonization. Rather than merely identifying the presence of specific policy instruments, it is essential to adopt an analytical procedure capable of assessing the overall configuration of the policy mix, its structural properties, and its capacity to foster transformations in complex sociotechnical systems.

Accordingly, this study adopts the analytical methodology proposed by Bessa and Gouveia (2023), which operationalizes the conceptual framework developed by Rogge and Reichardt (2016) into a systematic protocol consisting of successive stages of policy objective definition, instrument identification and classification, individual instrument analysis, interaction analysis, and policy mix evaluation.

This section presents the methodological approach adopted and describes its application to the analysis of public policies for the automotive industry and the promotion of sustainable mobility in Brazil and China.

3.1 RESEARCH DESIGN

This study adopts a qualitative, analytical-descriptive approach based on the policy mix analysis methodology proposed by Bessa and Gouveia (2023), which operationalizes the conceptual framework developed by Rogge and Reichardt (2016) for the analysis of public policies supporting sustainability transitions. This approach is adopted on the premise that the promotion of sustainable mobility results from the interaction of multiple policy instruments implemented over time, whose effectiveness depends not only on their individual effects but also on the way they are combined within a broader regulatory framework.

The unit of analysis comprises the policy mixes associated with public policies for the automotive industry and the promotion of sustainable mobility in Brazil and China. These cases were selected because of their strategic relevance to the global automotive industry[1] and

[1] The expansion of global value chains in the automotive industry has gradually shifted the production axis from advanced industrial economies toward emerging markets, increasing the importance of countries such as China

because they have pursued distinct industrial, technological, and environmental policy trajectories to address the transition toward low-carbon transportation systems. Although embedded in different institutional, economic, and technological contexts, both emerging economies provide valuable insights into the design and evolution of policy mixes (Liu et al., 2024).

The research is based on qualitative content analysis of primary and secondary sources. Primary sources include laws, decrees, regulations, government programs, strategic plans and other documents produced by governmental agencies. For Brazil, the analysis focuses on the regulatory frameworks of the Inovar-Auto, Rota 2030, and Green Mobility and Innovation (MOVER) programs, as well as other instruments that constitute the Brazilian industrial and environmental policy framework. For China, the analysis examines national development plans for the New Energy Vehicle (NEV) industry, State Council guidelines and other policy instruments related to industrial and environmental policies.

Secondary sources include books, peer-reviewed journal articles, book chapters, technical reports from international organizations, documents produced by industry associations, and specialized studies on industrial policy, innovation, sustainable mobility, and sociotechnical transitions. These materials provide the contextual background necessary to interpret the evolution of policies and the policy instruments identified.

3.2 POLICY MIX ANALYSIS

The analytical procedure follows the methodological protocol proposed by Bessa and Gouveia (2023), which operationalizes the analytical framework developed by Rogge and Reichardt (2016). The analysis is organized into five sequential stages (Figure 1): (i) definition of policy objectives; (ii) identification and classification of policy instruments; (iii) individual analysis of policy instruments; (iv) analysis of interactions among policy instruments; and (v) evaluation of the policy mix in terms of its characteristics and its potential to foster the transition toward sustainable mobility (Bessa; Gouveia, 2023).

and Brazil. While China has consolidated its position as the world's largest automotive producer and market, accounting for more than 30% of global sales, Brazil has established itself as one of the main automotive production hubs in Latin America.(Liu et al., 2024).

Figure 1 – Analytical Framework for Policy Mix Analysis

Source: Author's own elaboration

The first stage identifies the public problems addressed by each policy and the objectives pursued by the respective government programs. This step makes it possible to examine the evolution of automotive policy priorities, from goals primarily associated with industrial competitiveness to the progressive incorporation of objectives related to innovation, environmental sustainability, and transport decarbonization.

The second stage consists of identifying and classifying the policy instruments mobilized within each program. The classification is grounded in the policy design literature, particularly the contributions of Hood (1986), Howlett (2000, 2019), and Lascoumes and Le Galès (2007), distinguishing between substantive and procedural policy instruments, as well as the governmental resources they mobilize—namely authority, financial resources (treasure), information (nodality), and organizational capacity. The instruments are also categorized according to their economic, regulatory, informational, and organizational nature.

In the third stage, each policy instrument is examined individually with respect to its objectives, intervention mechanisms, target groups, and contribution to policy goals. This analysis seeks to understand how each instrument addresses barriers to innovation, stimulates productive investment, promotes energy efficiency improvements, encourages vehicle electrification, and enhances the competitiveness of the automotive industry.

The fourth stage focuses on the interactions among the instruments composing each policy mix. Relationships of complementarity, mutual reinforcement, overlap, redundancy, and potential conflict are examined, together with their evolution over time. Particular attention is devoted to identifying layering processes, understood as the gradual incorporation of new policy objectives and instruments into pre-existing institutional arrangements.

Finally, the fifth stage evaluates the policy mixes according to the analytical dimensions proposed by Rogge and Reichardt (2016). Particular emphasis is placed on consistency,

coherence, comprehensiveness, and credibility, assessing the degree of alignment among policy objectives, instruments, and governance mechanisms. The analysis also considers the cross-sectoral integration of public policies by examining their articulation with broader national strategies for industrial development, innovation, energy, climate, and infrastructure.

4 POLICY MIXES FOR SUSTAINABLE MOBILITY

This section examines the evolution of public policies for the automotive industry toward decarbonization in Brazil and China. The energy transition in the automotive sector of these emerging economies reveals contrasting institutional arrangements. While China has developed a dynamic policy mix, strongly coordinated by the state and oriented toward technological leadership in NEVs, Brazil has followed a trajectory characterized by institutional accumulation and layering, with ethanol playing a central role and an incremental transition supported by flex-fuel technology and the recent advances introduced by the MOVER Program.

4.1 THE CHINESE POLICY MIX

The evolution of China's automotive industrial policy represents one of the most comprehensive examples of the use of state-led policy mix coordinated among the Five-Year Plans to foster long-term technological and industrial transformation. Over the past four decades, the Chinese government has developed a policy framework characterized by the combination and continuous evolution of regulatory, industrial, technological, and innovation instruments, systematically adjusted to support strategic objectives related to economic development, international competitiveness, and the decarbonization of mobility (Peng; Li, 2022; Li, 2024; Chen et al, 2024).

This process began with the Reform and Opening-up policy launched in 1978 and was consolidated during the 1980s through the adoption of a strategy based on joint ventures (JVs) between foreign automakers and domestic firms. Commonly described in the literature as a strategy of "exchanging market access for technology" (market for technology), this approach conditioned access to China's rapidly expanding domestic market on the establishment of partnerships with local firms and the gradual internalization of manufacturing and technological capabilities (Donnelly; Collis; Begley, 2010).

Although this initial arrangement contributed significantly to building China's automotive manufacturing base, it failed to transfer core research and development (R&D) capabilities in the internal combustion engine (ICE) segment, thereby preserving the technological leadership of foreign automakers (Li, 2024). Industry plans have developed from the "Automotive Industry Policy" (1994), the "Automotive Industry Development Policy" (2004 and its revised version in 2009), to the "Medium- and Long-term Development Plan for the Automotive Industry" in 2017. The focus of China's automotive industry has progressively shifted from technology acquisition and industrial standardization toward independent research and development (R&D), the advancement of key component technologies, industrial restructuring, the gradual liberalization of import restrictions, and, more recently, the development of core technologies, intelligent mobility, connected vehicles, and international expansion (Chen et al., 2024).

To overcome patent barriers, mitigate urban air pollution, and strengthen energy security, the central government strategically shifted its focus toward NEVs, gradually moving from selective and protectionist policies to a more market-oriented and functionally driven policy framework (Peng; Li, 2022; Li, 2024). This transition illustrates the evolution of China's policy mix from a policy primarily aimed at protecting domestic industry to a more sophisticated arrangement combining innovation support instruments, regulatory standards, economic incentives, investments in charging infrastructure, environmental targets, and market-based mechanisms – most notably the Dual Credit Policy – while maintaining the State's strong coordinating role (Peng; Li, 2022; Li, 2024).

This trajectory demonstrates the gradual evolution of the Chinese policy mix, characterized by the successive incorporation of new policy instruments in response to technological, economic, and environmental changes. As summarized in Table 1, the Chinese policy mix evolved through three complementary and sequential stages (Peng; Li, 2022; Li, 2024).

Table 1 – Evolution of China's Automotive Industrial Policy Programs

Dimension	R&D Incubation Phase (1991–2008)	Pilot, Demonstration, and Direct Subsidy Phase (2009–2015)	Regulatory Transition and Market-Oriented Phase (2016–Present)
Paradigm	Paradigm of Scientific Capacity Building and National Energy Security	Paradigm of State-Led Market Creation and Economies of Scale	Paradigm of Functional Industrial Policy, Global Competitiveness, and Market-Based Regulation
Key Policy Instruments and Milestones	863 Program and Five-Year Plans. • "Three Verticals and Three Horizontals" Strategy. • Direct public funding for technological public goods.	• "Ten Cities, Thousand Vehicles" (TCTV) Program (2009). • Continued support for R&D combined with direct consumer subsidies. • Vehicle purchase tax exemptions.	• Dual Credit Policy (2017) • Gradual *phase withdrawal*) of direct subsidies. • NEV credit trading system and non-monetary incentives (*Right-of-Way*)
Technological and Industrial Dimension	• Initial focus on capability building in power electronics, batteries, and electric motors. • Overcoming patent-related constraints associated with ICE technologies.	• Sequential deployment of NEVs in public fleets (buses and taxis) to increase visibility and public acceptance. • Subsequent expansion of private demand and the initial charging infrastructure.	• Global leadership in NEV sales, exports, and total factor productivity (TFP). • Large-scale deployment of public charging infrastructure, complemented by electricity tariff incentives.
Focus of Government Intervention	• Supply-side: Basic R&D and the development of core technological capabilities.	• Demand-side: Market creation and protection, together with the promotion of early-stage economies of scale.	• Environmental and Functional Regulation: Market-based mechanisms, competitive R&D funding, and regulatory efficiency.

Source: Authors' own elaboration based on Peng and Li (2022) and Li (2024).

In this mature stage, the policy mix combined supply-side, demand-side, and environmental regulatory instruments (Hu et al., 2023). A key milestone was the implementation of the Dual Credit Policy (DCP) in 2017, which established fuel consumption targets and mandatory quotas for the production and commercialization of NEVs, creating a tradable credit system that penalizes manufacturers of conventional vehicles while rewarding

NEV production (Tian et al., 2024). This framework was complemented by substantial investments in public charging infrastructure, preferential electricity tariffs, tax incentives, and non-monetary right-of-way incentives, such as exemptions from vehicle registration restrictions, driving restrictions, and access to dedicated traffic lanes (Peng; Li, 2022).

Governance was based on a dual principal–agent model, combining strategic direction from the central government with policy adaptation by provincial and local governments, although challenges related to regional coordination and social contradictions within the production model remain (Liu; Xie, 2024). The State Council establishes the country's long-term industrial strategy, while the Ministry of Industry and Information Technology (MIIT) is responsible for designing and regulating automotive policies. The National Development and Reform Commission (NDRC) coordinates economic planning and strategic investments, and the Ministry of Finance provides fiscal incentives through tax exemptions and subsidy programs. At the subnational level, provincial governments play a crucial role in implementing national policies, developing industrial clusters, expanding charging infrastructure, and attracting domestic and foreign investment (Chen et al., 2024).

According to recent data from IEA (2025), domestic NEV sales increased from approximately 1.3 million units in 2020 to around 9.5 million in 2024, accompanied by a remarkable expansion of exports and the consolidation of domestic manufacturers, such as BYD, among the world's leading producers of electrified vehicles. China's automotive policy mix has contributed significantly to the country's emergence as the global leader in NEVs.

4.2 THE BRAZILIAN POLICY MIX

The Brazilian automotive industry was largely established through Foreign Direct Investment (FDI) by multinational corporations and integrated into global value chains without imposing conditions, such as mandatory R&D transfer or electrification quotas (Li, 2024). As a result, the country followed a distinct transition pathway shaped by the historical legacy of the National Alcohol Program (Proálcool) and the widespread adoption of flex-fuel technology, which continues to account for the majority of domestic vehicle sales (Dias et al., 2010).

Within this context, the Brazilian subsidiaries of foreign automakers, particularly European manufacturers, have historically adopted a defensive or analytical stance toward

battery electric vehicle (BEV) technologies (De Lara; Marx, 2018). While European headquarters restructured business models around electric mobility ecosystems and dedicated car-sharing services in response to the stringent environmental standards established under the and broader European Union climate policies, Brazilian subsidiaries justified postponing large-scale investments in battery electrification by emphasizing the favorable well-to-wheel environmental performance of sugarcane ethanol and the structural limitations of the country's charging infrastructure (Dias et al., 2010).

The automotive industry occupies a strategic position within Brazil's industrial structure owing to its substantial contribution to employment, income generation, and investment, as well as its extensive production linkages with sectors such as steel, chemicals, electronics, plastics, rubber, and technology-intensive services. Consequently, the sector has been the focus of successive industrial policies since the second half of the twentieth century, aimed at enhancing international competitiveness, stimulating productive investment, strengthening industrial capabilities and innovation, and, more recently, improving vehicle safety standards and energy efficiency (Truett; Truett, 2016).

The current MOVER Program constitutes the Brazilian government's principal industrial policy initiative for promoting fleet decarbonization and fostering innovation through sustainable technologies. Established by Law No. 14.902/2024 (Brasil, 2024a), the program reflects an incremental institutional trajectory, building upon previous automotive policies rather than replacing them through a process of radical reform.

Table 2 summarizes the recent evolution of Brazil's automotive industrial policy, highlighting how the MOVER Program combines multiple policy instruments (including regulatory, fiscal, technological, environmental, and innovation mechanisms) to pursue multiple policy objectives simultaneously. These objectives include enhancing industrial competitiveness, increasing investment in R&D, reducing transport-related emissions, and strengthening Brazil's integration into sustainable global value chains.

Table 2 – Evolution of Automotive Industrial Policy Programs in Brazil

Inovar Auto (2012-2017)	Rota 2030 (2018-2023)	Mover Program (2024-)
Paradigm Protection and Local Content	Paradigm Innovation-Driven Competitiveness	Paradigm Mission-Oriented Green Industrial Policy
Tax Incentives Local Content Requirements R&D Investment	Expanded R&D Energy Efficiency Vehicle Safety Predictability	Circular Economy Life Cycle Assessment Decarbonization Electrification Digitalization

Source: Authors' own elaboration.

The Inovar-Auto Program (2012–2017) was designed to strengthen domestic production by addressing the loss of competitiveness of the Brazilian automotive industry amid rising vehicle imports. Its policy mix relied predominantly on fiscal instruments, particularly reductions in the Industrialized Products Tax (IPI) conditional upon compliance with domestic production requirements, mandatory investments in research, development, and innovation (R&D&I), and the introduction of energy-efficiency targets. The program did not incorporate measures related to recyclability, electrification, or digitalization, maintaining a clear emphasis on domestic manufacturing capacity (Brasil, 2012; Brasil, 2026a).

The Rota 2030 Program (2018–2023) sought to enhance industrial competitiveness through innovation and efficiency, addressing the public policy challenges of limited technological modernization and regulatory uncertainty. Compared with its predecessor, the program expanded the policy mix by maintaining fiscal incentives, particularly tax credits linked to R&D investments, while increasing mandatory R&D expenditures, strengthening energy-efficiency requirements, incorporating vehicle emissions standards, and introducing initial incentives for electrification, recyclability, and digitalization. From a regulatory perspective, it also pursued partial alignment with international technical standards (Brasil, 2018; Brasil, 2026b).

The MOVER Program represents a shift toward a policy framework explicitly oriented to sustainable mobility. The program substantially broadens the complexity of the policy mix mobilized to address transport decarbonization while promoting Brazil's integration into global value chains. It preserves fiscal incentives (through financial credits linked to investments in

R&D and sustainability) and expands support for low-carbon technologies. At the same time, it introduces more comprehensive environmental and energy-efficiency criteria, incorporates life-cycle assessment and CO_2 emissions reduction requirements, establishes standards for recyclability and sustainable materials, explicitly encourages vehicle electrification and alternative propulsion technologies, promotes connectivity, automation, and embedded digital technologies, and reinforces the objectives of global competitiveness and international integration (Brasil, 2024a; Brasil, 2026c).

From the perspective of institutional change, the evolution of Brazilian automotive policy reflects a process of layering, whereby successive programs have built upon rather than replaced previous policy frameworks by progressively incorporating new objectives and instruments. Over time, the underlying policy problem has shifted from a narrow concern with industrial competitiveness to a broader emphasis on the green transition, integrating climate goals into the central rationale of automotive policy. The principal innovation of the MOVER Program lies not in the creation of entirely new fiscal incentives, but in the strategic combination of policy instruments aimed at enhancing industrial competitiveness and promoting transport decarbonization. Accordingly, the Brazilian state has preserved existing instruments while refining incentives, strengthening environmental requirements, and expanding innovation and regulatory mechanisms, resulting in a more comprehensive and sophisticated national policy mix.

Another defining characteristic of the MOVER Program is its cross-sectoral scope and policy integration. Rather than functioning as an isolated sectoral intervention, it is embedded within a broader sustainable development policy mix. The program is closely aligned with the NIB industrial policy – Nova Indústria Brasil, particularly Mission 3 (Sustainable Mobility), while also interacting with the National Policy on Climate Change (PNMC), the National Air Quality Policy (Law No. 14,850/2024), the Ecological Transition Plan (PTE), and the New Growth Acceleration Program (Novo PAC), especially regarding the renewal of public vehicle fleets (Brasil, 2024b; Velho, 2024).

The institutional arrangement is further complemented by innovation-oriented policies such as the Lei do Bem (Law No. 11,196/2005), as well as broader energy-transition initiatives, including the Future Fuels Program (Combustível do Futuro), RenovaBio, and national

strategies for developing critical minerals and rare-earth supply chains (Mindreau, 2025). This institutional convergence reinforces the transformation of Brazil's automotive regulatory model, shifting it from a policy primarily focused on production volumes toward an industrial policy centered on well-to-wheel decarbonization, technological innovation, and sustainable competitiveness.

By 2026, the Brazilian automotive market had reached significant milestones in the adoption of low-emission vehicles. Electrified vehicles, including BEVs, plug-in hybrid electric vehicles (PHEVs), and hybrid electric vehicles (HEVs) and flex-fuel hybrid vehicles (HEV Flex), recorded a 125% increase in first-semester sales compared with the same period of the previous year, growing at a rate approximately six times higher than that of conventional internal combustion vehicles. This expansion has been driven both by the increasing competitiveness and availability of BEVs, which accounted for more than half of all plug-in vehicle sales, and by the consolidation of HEV Flex as a strategic technological pathway for the domestic industry, combining regional energy security with the use of biofuels (ABVE, 2026).

This market expansion has been reinforced by complementary public policies aimed at accelerating fleet renewal and reducing the operating costs of passenger transportation. These include state-level exemptions from the Motor Vehicle Ownership Tax (IPVA) for fully electric vehicles and federal financing initiatives, such as the Move Brasil Táxi e Aplicativos program, which offers subsidized credit and extended repayment conditions for professional drivers (Brasil, 2026d).

From a policy mix perspective, however, the coexistence of long-established biofuel incentives with the relatively recent introduction of decarbonization policies has produced a layering process characterized by institutional tension. Decarbonization objectives have been superimposed upon pre-existing regulatory frameworks without comprehensive policy harmonization. Moreover, for many years, Brazilian policy instruments were largely limited to temporary reductions in import tariffs on electric and hybrid vehicles, while fully electric vehicles continued to face comparatively high IPI rates. This fiscal and regulatory asymmetry increased the overall cost of vehicle electrification, thereby slowing market diffusion and undermining the effectiveness of the country's transition toward sustainable mobility.

4.3 DISCUSSIONS

From the experiences analyzed, it can be inferred that different combinations of policy instruments, productive legacies, and local energy matrices condition the state's capacity to shape technological trajectories toward sustainable mobility and to reposition countries within global value chains.

In the Brazilian case, the interactions among policy instruments are markedly context-specific. The limited degree of vertical coordination between the federal government, which is primarily responsible for macro-level fiscal incentives, and municipal governments, which regulate urban mobility, charging infrastructure, and preferential road access, has constrained the emergence of stable niches for electromobility. Consequently, the Brazilian policy mix exhibits characteristics of policy drift, whereby formal policy arrangements remain relatively stable despite significant changes in the external technological environment, encouraging automakers to maintain an adaptive strategy centered on ethanol-based hybrid propulsion technologies.

In contrast, the Chinese policy mix is characterized by a higher degree of complementarity among policy instruments. Procedural instruments, particularly the institutional coordination established through partnerships involving central and local governments, universities, and automobile manufacturers, have reduced transaction costs and strengthened the implementation of substantive instruments, including direct purchase subsidies, industrial incentives, and regulatory measures.

As argued by Capano and Howlett (2020), the analysis of policy mixes should encompass not only the dynamics of introducing or removing policy instruments over time, but also the extent to which individual instruments simultaneously contribute to multiple policy objectives. In this regard, Table 3 synthesizes the principal interactions identified in the Brazilian and Chinese policy mixes, providing a systematic assessment of the complementarities, synergies, and potential tensions among the policy instruments examined.

Table 3 – Policy Mix Dynamics in Brazil and China

Variable	**Brazil** (Inovar-Auto / Rota 2030 / MOVER Program)	**China** (Five-Year Plans / DCP / NEVs)
Timeframe	2012 (Inovar-Auto), 2018 (Rota 2030), 2024 (MOVER Program)	1991 (863 Program), 2009 (TCTV), 2017 (Dual Credit), 2024–2026
Predominant Previous Policy Instruments	External tariffs, local content requirements, and vehicle-specific energy efficiency standards.	Joint ventures ("market for technology") and pilot public fleets.
Was there a complete replacement of policy instruments?	No. Although the programs succeeded one another following the expiration of their legal mandates, they preserved the core logic of tax incentives linked to R&D investment.	Partially. Direct purchase subsidies were gradually phased out by 2022 and replaced by the market-based DCP.
Was there layering?	Yes. Continuous layering of environmental and innovation objectives onto pre-existing fiscal incentive frameworks, without disrupting the existing biofuel infrastructure.	No, in the strict sense. Instead, a phased policy transition occurred, whereby the government progressively eliminated obsolete policy instruments as the NEV market reached technological maturity.
Was there a conversion or reorientation of policy objectives?	Yes. The MOVER Program transformed the previous emphasis on industrial protection and energy efficiency into a cross-sectoral industrial policy aligned with the NIB, particularly Mission 3 (Sustainable mobility for productive integration and well-being in cities).	Yes. The policy objectives were strategically reoriented from an assembly- and technology-absorption model toward global leadership and dominance in critical NEV component value chains.
Was there policy dismantling?	No. Support for biofuels and domestic production incentives was maintained and adapted to the decarbonization policy framework.	Yes. Deliberate discontinuation of direct fiscal subsidies to prevent rent-seeking behavior and market inefficiencies.

Source: Authors' own elaboration based on the analytical frameworks proposed by Capano and Howlett (2020) and Bessa and Gouveia (2023).

In the Chinese case, a symbiotic alignment can be observed between substantive and procedural policy instruments. The central procedural instrument – embodied in the Dual Principal-Agent governance model (Liu; Xie, 2024) linking the central government and provincial authorities – reduced transaction costs associated with the regional implementation

of substantive measures, such as the large-scale expansion of public charging infrastructure and the provision of right-of-way incentives. The replacement of direct purchase subsidies by the DCP in 2017 shifted part of the transition costs to automobile manufacturers, transforming regulatory obligations into drivers of productivity gains and global technological leadership (Tian; Wang; Zhu, 2024).

In the Brazilian case, the interaction among policy instruments reflects a trajectory that is strongly context-specific. The well-established biofuel infrastructure, particularly the ethanol/flex-fuel system, has acted as a buffering mechanism against the early disruption associated with BEVs. From an institutional perspective, this coexistence has generated episodes of policy drift, in which formal regulatory arrangements evolved more slowly than technological developments, encouraging domestic subsidiaries to adopt defensive innovation strategies centered on improving the well-to-wheel performance of ethanol-based propulsion systems.

The introduction of the MOVER Program represents an attempt by the Brazilian government to overcome a fragmented regulatory landscape through a process of coordinated policy patching. By establishing stringent vehicle life-cycle emissions assessment criteria, the program integrates substantive incentives, such as financial credits linked to R&D and environmental performance, with a broader procedural agenda structured around three complementary dimensions:

1. Cross-sectoral governance: MOVER is closely aligned with Mission 3 of the NIB strategy, the Ecological Transition Plan, the National Air Quality Policy and the Future Fuels Program, thereby strengthening policy coordination across industrial, environmental, and energy domains.
2. Technological neutrality: Rather than prescribing a single technological pathway – as observed in China's electrification-oriented strategy – the Brazilian policy mix preserves competitive technological neutrality, simultaneously supporting flex-fuel hybrid technologies, battery electric vehicles, and hydrogen fuel-cell technologies (Mindreau, 2025; Velho, 2024).
3. Acceleration of urban fleet renewal: Complementary initiatives, such as the Move Brasil Táxi e Aplicativos program, function as demand-side catalysts by facilitating the

replacement of high-use urban fleets. These measures complement state-level vehicle tax (IPVA) incentives and help mitigate market resistance to the adoption of low-emission vehicles.

Overall, whereas China has transformed state-led industrial planning into indigenous innovation capacity, enabling it to set global technological standards for NEVs, Brazil has developed a policy mix characterized by a high degree of regulatory complexity. This arrangement seeks to reconcile the preservation of the country's ethanol-based industrial and agro-industrial base with its integration into global electromobility value chains, turning the institutional layering of policy instruments into a mechanism for fostering an inclusive and competitive ecological transition.

The preliminary findings suggest that the effectiveness of sectoral transition policies depends less on the adoption of isolated policy instruments than on the state's ability to design, coordinate, and adapt coherent, consistent, and mutually reinforcing policy mixes that are responsive to technological change, institutional specificities, and the structural constraints faced by domestic industries.

5 CONCLUDING REMARKS

The objective of this study was to examine how interactions among policy instruments shape the technological trajectories of automotive industry decarbonization in emerging economies, drawing on the experiences of Brazil and China. The policy mix framework proved to be an appropriate analytical lens, as it enabled the examination of how interactions among policy instruments, combined with country-specific institutional and productive characteristics, influence alternative pathways toward transport decarbonization.

In Brazil, the evolution of automotive policy reflects a process of regulatory layering, whereby successive programs – Inovar-Auto, Rota 2030, and MOVER – have progressively incorporated innovation and decarbonization objectives into a pre-existing fiscal framework centered on the country's biofuel-based energy matrix. Rather than representing institutional weakness, the current design of the MOVER Program seeks to overcome historical regulatory fragmentation by adopting a technology-neutral approach based on a well-to-wheel life-cycle

perspective. This strategic orientation supports a pragmatic and inclusive green transition by reconciling flex-fuel hybrid technologies with the gradual expansion of electromobility.

The Chinese experience illustrates the effectiveness of state-coordinated strategic policy objectives, where substantive industrial incentives are strategically coordinated with procedural governance mechanisms to accelerate technological upgrading instead of merely expanding production. Rather than relying on isolated subsidies or protectionist measures, China progressively integrated regulatory, financial, innovation, and coordination instruments into a long-term industrial strategy. The transition from conventional automotive manufacturing to NEVs, therefore reflects a reconfiguration of the policy mix, not a replacement of industrial policy.

Brazil and China cases suggest that successful automotive industrial policy depends not merely on the number or type of policy instruments employed, but on their temporal accumulation, substantive complementarity, and procedural coordination. While both countries have progressively incorporated environmental and technological objectives into their automotive policy mixes, China has developed a more coherent and cumulative configuration in which substantive instruments are supported by strong procedural coordination and long-term strategic planning. Brazil, by contrast, illustrates a more adaptive policy trajectory, in which successive policy programs have incorporated new technological and environmental objectives. The comparison therefore suggests that policy-mix effectiveness is closely associated with the capacity to combine policy adaptation with institutional continuity and coordination.

The main contribution of this study is to show that the transition toward sustainable mobility is not only a technological challenge but also a policy-mix governance challenge. The effectiveness of a policy mix depends on its ability to upgrade and integrate the pre-existing structures with emerging technological frontiers, reconciling industrial competitiveness with global climate commitments, as its tools are able to progressively change what the existing industrial capabilities are used for.

This study is subject to certain limitations. Its qualitative nature and emphasis on the normative evolution of public policies preclude a direct econometric assessment of the impacts of individual policy instruments on greenhouse gas emissions, technological innovation, or

patenting activity. Future research could extend this analysis by examining the governance arrangements and actor networks associated with the MOVER Program, as well as by investigating how Brazil's institutional and federal governance structures shape the implementation and effectiveness of sustainable mobility policies.

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