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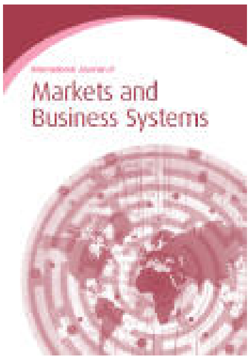


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# The electrification of passenger transport for sustainable mobility: challenges and opportunities from the perspective of key stakeholders

Alma Delia Torres-Rivera, Laura Alma Díaz-Torres

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# The electrification of passenger transport for sustainable mobility: challenges and opportunities from the perspective of key stakeholders


## Alma Delia Torres-Rivera*

Unidad Profesional Interdisciplinaria de Energía y Movilidad,
Instituto Politécnico Nacional,
Ciudad de México, 07738, México
ORCID: 0000-0002-0924-041X
Email: atorresri@ipn.mx
*Corresponding author

## Laura Alma Díaz-Torres

Escuela Superior de Medicina,
Instituto Politécnico Nacional,
Ciudad de México, 07738, México
ORCID: 0000-0003-4602-4713
Email: ldiazt1600@alumno.ipn.mx



**Abstract:** This study explores the main challenges and opportunities of electrifying public transport in Mexico City from the perspective of key stakeholders. A structured discussion was conducted with public, private, and academic experts. Their responses were analysed thematically and organised into five analytical axes: regulatory-institutional, technological-operational, social, economic-financial, and environmental. The findings highlight the need for a coherent legal framework, robust infrastructure, innovative financing, social inclusion, and integration with renewable energy sources. The study adopts a systemic perspective of electromobility, emphasising that electrification involves not only vehicles but also governance, supply chains, and equity. The analysis contributes practical insights and proposes future research lines on circular economy, battery lifecycle, collaborative governance, and financial sustainability, offering valuable input for urban transport policy and sustainable mobility planning in Latin America.



**Keywords:** battery lifecycle management; circular economy in transport; collaborative governance; electric mobility; electrification of public transport; financial sustainability in mobility; gender inclusion in mobility planning; renewable energy integration; stakeholder perspectives; sustainable urban transport.

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**Biographical notes:** Alma Delia Torres-Rivera received her PhD in Education from Universidad Rosario Castellanos. A faculty member at IPN since 1989, she specialises in Social Innovation and Sustainable Business Models.

Recognised as a Level 1 Member of Mexico's National System of Researchers (SNII-I).

Laura Alma Díaz-Torres is an Artificial Intelligence engineer currently pursuing a master's degree in Bioethics at the Instituto Politécnico Nacional and a specialisation in Data Science at the Tecnológico de Monterrey. Her research focuses on applying predictive models for public transportation management and energy transition, emphasising sustainable mobility and artificial intelligence. She has published papers and book chapters in these areas and actively participates in data analysis projects to optimise transportation and electromobility.

## 1 Introduction

In the context of post-pandemic recovery and global economic shifts, adopting sustainable strategies to reduce greenhouse gas and pollutant emissions is crucial for improving urban air quality. Between 14% and 16% of global carbon dioxide ($CO_2$) emissions originate from the transport sector. Specifically, passenger transport accounts for approximately 45% of transport-related emissions – equivalent to 6% and 7% of global emissions. Within the land transport category – such as private cars and buses – it is estimated to represent around 4–5% of global emissions. These figures highlight the sector's significant role in climate change and the urgency of promoting sustainable mobility technologies and policies (IEA, 2023; IPCC, 2022).

In response to these challenges, the electrification of passenger transport has emerged as a key strategy for reducing the environmental impact of fossil fuel dependency. This shift has led to the implementation of policies and incentives to encourage the adoption of electric vehicles (EVs), expand charging infrastructure, and drive technological innovation. Transport electrification reduces particulate emissions, improves air quality, and mitigates public health risks. Additionally, it supports the integration of renewable energy sources into the electricity grid, although it also raises challenges related to energy storage and supply intermittency. Across the globe, countries such as Germany, Denmark, Norway, Australia, USA, and China are leading efforts to incorporate renewable energy into transport systems through comprehensive measures that promote EV adoption, enhance energy resilience, meet climate targets, and foster long-term sustainability (C40 Cities, 2020).

Beyond environmental benefits, transport electrification is reshaping supply chain management by encouraging sustainable market dynamics and enabling applied research and technology transfer. Coordinated efforts between governments, industry, and urban planning authorities are essential to decarbonise transport systems and redefine the energy matrix. In this context, electrifying transport with renewable energy sources is imperative for cities aiming to contribute to emissions reduction goals and sustainability objectives outlined in the 2030 Agenda for Sustainable Development and other international commitments (Corvera and González, 2023).

Regional experiences provide valuable insights into the progress and challenges of this transition. For instance, Messina et al. (2022) highlight electromobility trends in four Latin American megacities, each adopting distinct approaches to cleaner and more efficient transport. In Buenos Aires, a pilot phase involving 95 electric buses is underway. São Paulo leads in the number of electric cars and trucks, with 73,000 electrified vehicles and a remarkable 77% growth in EV sales in 2021 compared to the previous year. Colombia aims to deploy 600,000 EVs by 2030, supported by a robust regulatory framework (Foss and Saebi, 2018). Meanwhile, Mexico City has developed the region's most extensive charging infrastructure, with 1161 public stations, reaffirming its goal of achieving a 100% EV transition by 2050 (García-Olivares et al., 2018).

These Latin American experiences also underscore the importance of comprehensive planning and integrated policies to support the expansion of electricity generation capacity and infrastructure to meet rising EV demand. The electrification of public transport is a complex, multidimensional phenomenon involving regulatory, technological, economic, environmental, and social aspects, whose integration is essential to ensure effective and equitable implementation (IEA, 2023; GIZ, 2022). However, the region faces structural barriers – including the absence of tailored regulatory frameworks, infrastructure gaps, limited financing, and weak institutional coordination. Examples from Colombia, Chile, and Mexico demonstrate that a successful energy transition in public transport requires collaborative governance capable of coordinating multiple actors and levels of government (Assefa, 2020; ECLAC, 2020; Messina et al., 2022; Rozas Balbontín, 2022).

An essential dimension of this transition lies in battery technologies and material supply chains. Rajaeifar (2022) emphasises the importance of reusing lithium-ion batteries at the end of their life cycle, as battery repurpose can significantly reduce carbon emissions associated with storage capacity (Zagorodny, 2023). Nevertheless, concerns persist regarding the critical nature of materials such as lithium, cobalt, and natural graphite, whose supply risks could result in shortages and price volatility. In line with this, Duehnen (2020) stresses the need for high-performance, low-cost batteries to ensure sufficient driving range and fast charging capabilities. Implementing strategies for an environmentally friendly, flexible, cost-effective battery supply, usage, and recycling is also necessary.

Therefore, a long-term transport electrification plan is required to transcribe political cycles, encourage private-sector investment, and activate electric market dynamics. Moreover, when effectively managed, integrating distributed energy resources can enhance electricity market performance through incentives and intelligent metering systems that enable real-time grid interaction.

Given the complexity of the challenges outlined, experts have a broad consensus that electromobility is a multidimensional phenomenon requiring the integration of collaborative governance, circular economy principles, financial sustainability, and social justice approaches. Accordingly, this analysis is structured around five thematic axes: regulatory-institutional, technological-operational, social, economic, and environmental. Based on the findings, strategic recommendations and future research directions are proposed to strengthen public policy planning, implementation, and evaluation of electric mobility.

This paper analyses the actions driving technological integration in the electrification of passenger and freight transport. From the perspective of key stakeholders, these actions present strong potential to reduce the carbon footprint and support sustainable transformation. The paper is structured as follows: Section 1 explores electromobility within the framework of the Sustainable Development Goals (SDGs); Section 2 describes the analytical model, and the methodology is presented in Section 3. Section 4 presents the findings, and Section 5 offers conclusions and future research directions.

## 2 Theoretical bases

The electrification of transport is a key strategy in the transition towards more sustainable, safe, and resilient urban mobility systems. As cities worldwide face increasing environmental pressures, rising energy demands, and complex social challenges, the need to decarbonise the transport sector has become urgent. Electrification is a response to climate change mitigation goals and a catalyst for rethinking urban transport systems' structure and operation. By reducing greenhouse gas emissions, improving energy efficiency, and lowering levels of air pollution, electric transport contributes directly to public health, energy security, and quality of life (Thakore et al., 2015). Furthermore, electrification intersects with broader sustainability agendas, including the transition to renewable energy sources, the digitalisation of infrastructure, and the pursuit of inclusive economic development. In this context, electromobility has gained increasing prominence in international agendas as a comprehensive and multidimensional approach that extends beyond the simple incorporation of electric vehicles into transport fleets and calls for systemic change in policy, planning, and governance.

According to UN-Habitat (2021), "Electric mobility is increasingly being promoted in cities around the world – and brings with it many opportunities if designed and implemented well" (p.14). This statement highlights the importance of integrating electric mobility into compact urban planning aligned with the Avoid-Shift-Improve (ASI) framework. Electrification must prioritise public transport and active and shared mobility rather than focusing exclusively on private vehicles. "Electric mobility is primarily an improved strategy, enhancing vehicle energy efficiency. Electric mobility can also contribute to the 'Shift' pillar" (UN-Habitat, 2021, p.5).

This comprehensive understanding allows us to view electromobility not as an isolated technological shift but as a sociotechnical innovation strategy involving institutional decisions, intelligent infrastructure, economic sustainability, and social justice. From this perspective, it becomes possible to analyse how organisations address this transition's structural challenges, particularly in business sustainability and adaptive strategic planning in the face of a changing energy environment.

### *2.1 Business sustainability, strategic resilience, and collaboration in value chains*

Since the late 1980s, environmental and social issues have increasingly been recognised as strategic factors in business management (Manring and Moore, 2006). The connection between economic performance and environmental impact has opened opportunities for sustainable development (Messina et al., 2022). As firms acknowledge their strategic role in building a shared future (Rajaeifar et al., 2022), the need to implement strategic plans that enhance competitiveness while advancing sustainability becomes evident. Hart and Milstein (2003) emphasise that sustainability must be embedded in strategic planning (Saravia, 2018).

Strategic planning often involves transforming perceived threats and weaknesses – such as changing environmental or social conditions – into opportunities and strengths, ultimately contributing to competitive advantage. Paradoxically, organisations tend to improve resource efficiency by shifting focus away from ecological footprints and addressing demands related to material use and inputs (Messina et al., 2022; Rajaeifar et al., 2022). So, it redefines growth in the context of a more sustainable and dynamic market.

From the perspective of Freudenreich et al. (2020), businesses must develop resilience, defined as the ability to survive, adapt, and grow amid turbulent change while simultaneously increasing the economic, social, and environmental value of their business models (Rothaermel and Hess, 2007). In collaborative business environments, sustainability strategies generate systemic benefits and can drive competitive advantages when:

- investments aim to develop internal sustainability capacities
- partnerships are forged in uncertain and complex settings
- firms position themselves as sustainable suppliers in global value chains (Messina et al., 2022).

Organisational resilience and the capacity to integrate, develop, and reconfigure competencies are critical to responding to rapidly changing markets and disruptive innovations. These capacities are shaped across personal, organisational, and network levels (Rothaermel and Hess, 2007). Regardless, key obstacles to managing disruptive change effectively at the managerial level include limitations in business models and innovation capabilities (Christensen, 1997). In line with Yolles (2018), sustainability should be conceptualised not merely through discrete pillars – economic, environmental, and social – but as the result of coevolutionary interactions between autonomous and interdependent systems.

From a comprehensive view, this aligns with the five conceptual axes proposed in this study, which serve as an analytical framework to interpret the obstacles to transition to electromobility and the perspectives of the key actors in its implementation across diverse urban settings. To better understand the transition toward electromobility, examining how internal organisational dynamics can enhance or limit a firm's ability to engage in this shift is essential. Thakore et al. (2015) propose five key enablers to address structural barriers in the context of sustainability: Initiative, Investment, Incentive, Information, and Innovation ("5-IN"). These elements determine success in energy efficiency in the decarbonisation process. The interaction between institutional leadership, financial mechanisms, stakeholder engagement, and policy coherence reinforces the importance of a comprehensive, multi-level governance approach to implementing electromobility strategies based on the sociopolitical dynamics that influence the adoption of low-carbon technologies in urban systems. The following section will explore how these capabilities affect strategic planning and innovation in rapidly changing contexts.

## *2.2 Organisational capabilities and disruptive innovation*

To better understand the transition toward electromobility, examining how internal organisational dynamics can either enhance or limit a firm's ability to engage in this shift is crucial. While external factors such as regulations, technology, financing, and governance are important, the success of any sustainability strategy ultimately relies on a firm's internal capacity to anticipate changes, integrate innovation, and respond to emerging challenges. They need a comprehensive understanding of the organisational processes, competencies, and values that influence strategic behaviour, especially in disruptive environments. The following section will explore how these capabilities affect strategic planning and innovation in rapidly changing contexts.

Strategic planning scenarios anticipating future market conditions are essential for navigating social and environmental uncertainty and addressing unmet consumer needs (Saravia, 2018; Rozas Balbontín, 2022). In this context, internal processes, stakeholder relations, investor engagement, and value propositions must be integrated as central components of business strategy (Rothaermel and Hess, 2007; Rozas Balbontín, 2022).

An organisation's ability to navigate disruptive change depends on its resources, processes, and values. In the early stages, firms rely on resources; as they mature, their more structured processes become, and their values are more clearly defined, shaping their organisational culture. Christensen (1997) stresses that transforming a company's processes, business models, and values are difficult but essential to achieving competitive advantage.

One of the main drivers of 'creative destruction' in today's rapidly evolving global markets is the globalisation of communication technologies, which enables the formation of interconnected business networks. These inter-organisational alliances foster the coordinated development of core competencies, allowing firms to increase their scale, improve market positioning, and act as unified entities (ECLAC, 2020).

Sustained organisational learning and knowledge exchange through networked collaboration is vital for maintaining strategic relevance in the face of disruptive change. Partnerships with stakeholders from academia, the private sector, and public institutions strengthen knowledge networks and promote innovation. Inter-firm cooperation is increasingly recognised as a driver of technological resilience, sustainable development, and inclusive urban communities (Manring and Moore, 2006).

Electromobility has thus emerged as a strategic response to climate change, urban sustainability, and energy transformation challenges. Recent studies show that its implementation demands more than technological change; it requires reconfiguring governance systems, business models, and infrastructure (Duehnen, 2020; Messina et al., 2022).

## *2.3 Conceptual axes for analysing electromobility*

Based on the reviewed literature, five conceptual axes are proposed to analyse the opportunities and challenges of electromobility from a multidisciplinary perspective. These axes also guided the structure of the expert roundtable discussion and the subsequent analysis:

1 *Regulatory-institutional axis*: Focuses on the need for clear, stable, and adaptive regulatory frameworks, along with inter-institutional coordination across multiple levels of government. Collaborative, multilevel governance is key to overcoming regulatory fragmentation and ensuring coherent decision-making in complex urban environments (GIZ, 2022; Rozas Balbontín, 2022).

2 *Technological-operational axis*: Includes infrastructure for charging, vehicle range, staff training, and maintenance systems (García-Olivares et al., 2018; Rajaeifar et al., 2022). It also incorporates the concept of disruptive innovation (Christensen, 1997) to understand the challenges operators face in adopting new technologies.

3 *Social axis*: Informed by social justice perspectives, this axis highlights the importance of gender inclusion, citizen participation, and equitable access to electrification's benefits. C40 Cities (2020) advocates for inclusive transitions that avoid reproducing existing inequalities and promote the participation of historically excluded groups. Women's representation in electric mobility's design, operation, and regulation is essential for institutional quality and social sustainability.

4 *Economic-financial axis*: This axis addresses financing mechanisms such as public-private partnerships, green bonds, and sustainable investment funds (Hart and Milstein, 2003; Salkuti, 2023). It also includes organisational sustainability and financial resilience, particularly for adaptive business models in urban contexts (Foss and Saebi, 2018).

5 *Environmental axis*: Examines the impact of electrification on climate change mitigation, vehicle life cycle analysis, and sustainable battery management. It promotes a circular economy approach, particularly regarding the reuse and recycling of lithium-ion batteries and other critical materials (Freudenreich et al., 2020; Rajaeifar et al., 2022) and underscores the importance of integrating electromobility with renewable energy sources (IEA, 2023).

These conceptual axes are grounded in contemporary frameworks such as collaborative governance (GIZ, 2022), sustainable and adaptive business models (Foss and Saebi, 2018; Hart and Milstein, 2003), and the circular economy applied to critical resource management (Rajaeifar et al., 2022). They also reflect key commitments to social inclusion and gender equity in mobility systems (C40 Cities, 2020). Together, these perspectives provide a robust and multidimensional foundation for analysing electromobility within the Latin American urban context.

In this regard, Täuscher and Chafac (2016) propose that business models should not be treated as static structures, but as dynamic systems characterised by feedback loops, interdependencies, and evolving relationships between actors. They highlight the value of scenario-based simulation approaches to support decision-making under conditions of uncertainty, particularly in sectors undergoing technological disruption. From this perspective, sustainable business models in the electromobility sector must anticipate how policy incentives, user behaviour, technological change, and infrastructure availability interact over time. Simulation tools enable the evaluation of these variables and help design financially viable strategies capable of adapting to systemic complexity and market fluctuations.

The following section outlines the methodological approach, building upon this foundation, adopted to explore the electrification of public transport through the lens of the key actors involved in its design, implementation, and evaluation. By operationalising these theoretical constructions within an exploratory qualitative framework, the study seeks to capture the richness and complexity of stakeholders' perceptions and lived experiences, offering empirically grounded insights into the challenges and opportunities that shape sustainable urban mobility in the region.

# 3 Methodology

## *3.1 Data collection*

Empirical data were collected through a thematic roundtable discussion to explore the challenges and opportunities surrounding the electrification of public transport. Seven experts selected by invitation based on their experience in key areas of electric mobility in Mexico City, including public policy, vehicle supply, infrastructure development, and project management, participated in the session.

The selection of two experts involved in the electrified lines of the Metrobús system is shown in Table 1. Representatives from electric vehicle supplier companies were selected due to their direct knowledge of the technological offerings and the supply chain barriers affecting the implementation of electric vehicles. The participation of these experts ensures a comprehensive and specialised understanding of the electromobility issue under study. Participants were informed in advance about the objectives and topics of the roundtable to ensure an informed and productive discussion.

**Table 1** Description of roundtable participants by area of expertise

| *Expert area* | *Description* |
|---|---|
| Electrification project management | Two experts with experience in managing and implementing passenger transport electrification projects |
| Electric vehicle supplier companies | Two representatives from electric vehicle supplier companies |
| Infrastructure development for electromobility | Two experts in infrastructure development, construction, and maintenance for electromobility |
| Public policy | One expert in public policy, regulations, incentives, and normative frameworks |

Participants were selected by invitation.

During the conversation, each expert addressed the key topics in a roundtable format to foster an open and dynamic exchange of ideas. This was followed by an interactive discussion among all participants, guided by a combination of open-ended and targeted questions to steer the dialogue. The session was recorded with informed consent and conducted in a roundtable format that encouraged open dialogue and exchange across institutional and disciplinary boundaries. The conversation was guided and flexible, allowing for structured input and spontaneous reflection. A full discussion transcript was produced from the audio-visual recording, serving as the primary source of empirical material for the subsequent analytical process.

## *3.2 Data analysis*

The empirical material was analysed through a rigorous process of open coding and thematic categorisation, guided by the constant comparative method from Grounded Theory (Glaser and Strauss, 1998). Although the objective of this study was not to generate a formal theory, this methodological approach provided a robust framework for identifying recurring patterns, significant discursive units, and relationships between emerging concepts within the participants' narratives of participants who participated in the discussion held on April 26, 2024.

The first phase involved open coding, during which the transcript was examined line by line to segment the data into meaningful units. Each unit was assigned a code that captured the participants' core ideas, concerns, or interpretations. Coding was conducted in the original language to preserve the semantic depth of the data used by the speakers as closely as possible. In the second phase, a constant comparison process was employed. Each newly assigned code was systematically compared with existing codes to refine its meaning, identify redundancies, and detect convergences or divergences across participants. This iterative process facilitated the progressive grouping of codes into broader, more abstract categories, allowing for data reduction while preserving conceptual nuance and heterogeneity.

Analytical memos were written throughout the process to record emerging insights, interpretive hypotheses, and theoretical questions. These memos served as an audit trail of the analytic decisions and a reflective space to document shifts in interpretation and linkages across categories.

### *3.3 Thematic structuring and validation*

Once the categories had been consolidated, they were organised into thematic matrices aligned with the five analytical axes established in the theoretical framework. Each matrix consisted of rows for individual participants and columns for subthemes within each axis, allowing for comparing viewpoints across different roles, sectors, and areas of expertise. This matrix structure enhanced the triangulation of perspectives and provided a systematic means to synthesise the data.

Although this study does not strictly aim to develop a grounded theory, the constant comparative method was used as a rigorous strategy for the systematic and transparent interpretation of qualitative data. The focus was not on generating abstract theoretical constructs but on identifying meaningful patterns, organising the discourse, and contrasting perspectives to capture the complexity of the phenomenon under study. This analytical approach contributed to the internal validity of the findings by supporting iterative categorisation, reflective memoing, and the cross-validation of interpretations.

Finally, the categories were validated using a saturation criterion, whereby no new significant themes or distinctions emerged during further data review. The resulting analytical framework provides a structured synthesis of the convergent and divergent perspectives voiced by participants, offering insights into the main challenges, strategic opportunities, and enabling conditions for a sustainable and inclusive transition to electric mobility in Mexico City.

While this study employed a qualitative, exploratory design based on thematic analysis, future research may complement this approach with quantitative or simulation-based methods. Täuscher and Chafac (2016) suggested scenario-based models could support evaluating business strategies under uncertainty. Similarly, Thakore et al. (2015) demonstrate the value of using survey instruments and factorial analysis to identify converging barriers among diverse stakeholders. These methodological extensions could enrich the analysis of electromobility transitions in future multi-actor studies.

## 4 Results

The following are the results from analysing the participation recorded during the discussion. The key actors' perceptions and proposals were grouped into five thematic areas: regulatory-institutional, technological-operational, social, economic-financial, and environmental.

Table 2 presents the correspondence between frequently mentioned strategies and their associated conceptual axes. This thematic organisation provides a structured lens to interpret the factors influencing public transport electrification from a multidimensional perspective. The matrix highlights electromobility's multidimensional nature and key stakeholders' central concerns. The analysis reveals a shared concern for ensuring financial viability, overcoming technological barriers, and establishing a supportive regulatory framework. However, to a lesser extent, the social axis also emerges, particularly concerning talent development and user engagement. Five thematic axes were analysed in greater depth based on the frequency and relevance of the strategies discussed. The first corresponds to the policy and institutional dimension.

**Table 2** Relationship between frequency of strategies mentioned and conceptual axis

| *Factors* | *Frequency* | *Related conceptual axes* |
|---|---|---|
| Strategic planning for disruption | 19 | Regulatory-institutional/Economic-Financial |
| Infrastructure challenges | 18 | Technological-Operational |
| Innovation in business models | 17 | Economic-Financial/Technological-Operational |
| Cost-benefit assessment | 16 | Economic-Financial |
| Public-Private Partnerships | 15 | Regulatory-Institutional/Economic-Financial |
| Technological advances and innovations | 14 | Technological-Operational |
| Talent development | 13 | Social/Technological/Operational |
| Tax incentives | 12 | Regulatory-Institutional/Economic-Financial |
| International collaboration | 11 | Regulatory-Institutional/Environmental |
| Financial incentives and subsidies | 10 | Economic-Financial |
| Regulatory support and market development | 9 | Regulatory-Institutional |
| Low-interest loans | 8 | Economic-Financial |
| Volume purchase agreements | 7 | Economic-Financial |
| Energy cost management | 6 | Economic-Financial/Environmental |

### 4.1 Policy and institutional axis

Participants emphasised that one of the main barriers to implementing electromobility in Mexico is the absence of a robust and specific regulatory framework for electric transport. Existing laws were described as fragmented and misaligned with the particularities of electric public transport, generating uncertainty for operators and technology providers.

Among the points of most remarkable consensus was the need for strategic planning to prevent service interruptions. Experts highlighted the relevance of having national and local policies that anticipate risks, optimise system performance, and guarantee operational continuity. In this context, Public-Private Partnerships (PPPs) were essential for co-financing projects and enabling large-scale implementation.

A critical limitation was also identified as the lack of coordination between different levels of government – federal, state, and local. This misalignment hinders decision-making and delays the deployment of charging infrastructure, procurement processes, and long-term investment strategies.

### *4.2 Technological and operational axis*

Several structural challenges were identified from a technical and operational perspective. These include insufficient charging infrastructure, limited grid capacity, and the need for tailored preventive maintenance schemes for electric vehicles. Industry stakeholders emphasised the importance of investing in charging stations, maintenance networks, and energy management systems alongside specialised training for technical personnel.

Collaboration between the public and private sectors was key to accelerating the deployment of clean technologies and modernising operational processes. Experts stressed that current route optimisation and traffic management efforts prioritise vehicle efficiency but often overlook opportunities for innovation. Participants advocated adopting real-time monitoring technologies and predictive maintenance systems to anticipate failures and maintain service quality. In addition, the need for risk management protocols, rapid response mechanisms, and crisis recovery strategies was underscored to mitigate the impact of operational disruptions and improve system resilience.

### *4.3 Social and governance axis*

Beyond the technical and regulatory aspects, participants underlined the need to incorporate social dimensions into the planning and implementation of electromobility. Communication campaigns, public education strategies, and participatory decision-making processes were recommended to strengthen citizen engagement and promote social ownership of electrification projects.

A recurring concern was the fragmented nature of governance structures and the absence of clearly defined responsibilities among institutions and market actors. This lack of coordination creates bottlenecks in project implementation and limits the development of a shared strategic vision.

Drawing on the perspectives of Fullan (2007) and Bandura (1986), participants argued that the transformation of socio-technical systems requires the active involvement of social actors in agenda-setting, technological adoption, and trust-building. The absence of inclusive, intersectoral spaces for dialogue was seen as an obstacle to innovation, collaboration, and institutional legitimacy.

While the importance of including women in male-dominated sectors like transport and energy was acknowledged, participants noted that gender inclusion remains marginal and often disconnected from broader technology development strategies. In governance, there was strong support for collaborative, multi-level models involving government, industry, and communities in co-creating solutions.

### 4.4 Economic and financial axis

The economic axis concentrated on various concerns about the affordability and sustainability of electrification efforts. Despite the long-term savings in energy and maintenance, the high upfront cost of electric fleets was consistently mentioned as a significant obstacle.

Experts highlighted the need for accessible financial instruments, such as subsidies, tax exemptions, and low-interest loans, to facilitate the adoption of clean technologies. They also emphasised the importance of long-term cost-benefit analyses to support policy and investment decisions, particularly regarding fossil fuel dependence and public health.

Cross-sectoral collaboration was identified as a valuable strategy for distributing financial risks, attracting investment, and ensuring the economic viability of innovation in public transport systems.

### 4.5 Environmental and strategic axis

Although electromobility reduces emissions such as CO2, PM10, and PM2.5, experts cautioned that its long-term environmental benefits depend on addressing issues across the entire value chain. Of particular concern was the lack of battery recycling and reuse strategies, which could undermine the sustainability gains of electrified transport.

Rajaeifar (2022) highlighted the potential of second-life batteries to reduce the sector's carbon footprint. However, they noted that their practical use depends on regulatory clarity, technical interoperability, and robust traceability and waste management systems. In addition, experts stressed the strategic importance of planning for the sustainable use of critical materials such as lithium, cobalt, and natural graphite. Without such planning, new dependencies and geopolitical vulnerabilities could emerge.

The integration of circular economy principles – such as reuse, refurbishment, and recycling – into public policy and business models was proposed to maximise environmental benefits. Participants also discussed the role of emerging technologies, including vehicle-to-grid (V2G) systems, smart grids, distributed generation, and energy storage solutions. However, they emphasised that realising the potential of these technologies requires inter-institutional coordination, regulatory support, and clear incentives for their implementation.

## 5 Discussion

The results obtained in this study demonstrate that while the electrification of public transport is recognised as a strategic necessity by key stakeholders, it faces structural challenges that extend far beyond technology. The transition toward electric mobility requires effective alignment between regulatory frameworks, technical capabilities, financing mechanisms, and political will – factors consistent with earlier findings in Latin American contexts (Assefa, 2020; Saravia, 2018; GIZ, 2022).

A typical regional weakness became evident on the regulatory and institutional axis: the absence of coherent and multi-level regulatory instruments. Rozas Balbontín (2022) argues that electromobility cannot advance without an integrated governance framework that facilitates decision-making and fosters trust between public and private actors.

At the technological-operational level, the findings align with previous studies that point to limitations in the electric vehicle range and the shortage of technical skills in urban transport systems (García-Olivares et al., 2018; Rajaeifar et al., 2022). Participants highlighted that infrastructure adaptation and workforce training are often underestimated in early planning.

From a social perspective, the results confirm that electromobility initiatives have not systematically integrated participatory and inclusive approaches. Despite the literature recognising the importance of gender equity and public involvement (C40 Cities, 2020), these elements remain marginal in institutional practice. A noteworthy contribution from participants was the proposal to link electromobility with corporate social responsibility – suggesting a model where sustainability, technology, and inclusion are co-constructed.

On the economic front, the persistence of high initial investment costs and limited access to funding hinders large-scale adoption. This is consistent with prior research on barriers to disruptive innovation in public services (Christensen, 1997; Foss and Saebi, 2018). Nonetheless, participants offered collaborative financing proposals tailored to local contexts, allowing new co-financing schemes.

Finally, in the environmental and strategic axis, the study reinforces that electrification alone does not guarantee sustainability. The environmental impact depends on the energy matrix and how electromobility is embedded in long-term urban policy. A shift in perspective is required – from a narrow focus on electric vehicles to a broader commitment to urban energy transition (Corvera and González, 2023).

The findings are consistent with the barriers Thakore et al. (2015) identified, who highlight the lack of leadership, insufficient institutional coordination, and a lack of environmental responsibility as structural impediments to accelerating progress in electrifying electric passenger transport. Hence, governance capacities facilitate the deployment of electromobility in fragmented institutional contexts. While this study focuses on Mexico City, the findings can be cautiously extrapolated to other Latin American urban contexts with similar institutional conditions. However, further comparative research is recommended to strengthen external validity and explore context-specific dynamics.

### *5.1 Implications for urban sustainable mobility*

Beyond these findings, electromobility has substantial implications for urban mobility, particularly regarding technological transformation, infrastructure readiness, and systemic integration. Transforming transport systems toward sustainability has the potential to reduce carbon emissions and reshape energy consumption patterns in cities.

The successful expansion of electromobility also depends on the design of adaptive and financially resilient business models. Täuscher and Chafac (2016) argue that sustainable innovation requires scenario-based simulation tools to anticipate performance under uncertainty, especially when multiple actors and long-term investments are involved. Applying this perspective to electric transport systems highlights the need to evaluate the dynamic interactions between infrastructure, user demand, policy incentives, and technological change. Such modelling can support strategic decisions about tariff structures, ownership models, and financing mechanisms while accounting for potential lock-in effects and economies of scale that emerge as adoption increases. This approach reinforces the importance of flexible policy design and iterative learning to enable viable transitions in complex urban environments.

The first key contribution of this study is to underscore that deploying electric vehicles (EVs) requires a robust and resilient electricity grid. This includes the availability of high-capacity charging infrastructure, integration of renewable energy sources supported by long-life batteries and storage systems, and the efficient management of smart grids to balance supply and demand. Technologies such as V2G, which enable bidirectional energy exchange, can also enhance system stability and resilience.

The findings suggest that advancing public transport electrification depends on comprehensive public policy frameworks that ensure grid stability, service continuity, and technological standardisation. These include regulatory instruments for implementing subsidies, tax exemptions, incentives to adopt EVs, and investment in interoperable infrastructure and energy storage technologies. Public-private partnerships and policy coherence are essential to support a smooth transition.

Governments can accelerate innovation, lower costs, and strengthen local capacities by investing in developing technologies related to electrification, energy storage, and intelligent grid systems. Fostering international collaboration and bilateral agreements can unlock new opportunities for infrastructure development, technical cooperation, and knowledge transfer in sustainable urban mobility.

## 6 Conclusions and recommendations

This study adopted a qualitative and participatory approach to exploring the challenges and opportunities associated with electrifying public transport in Mexico City. Based on the perceptions of key actors, five strategic axes – regulatory-institutional, technological-operational, social, economic, and environmental – were identified that collectively shape the trajectory of urban electromobility.

The findings show that although there is a broad consensus on the urgency of transitioning toward electric mobility, significant structural barriers persist. These include the absence of a specialised regulatory framework, insufficient technical infrastructure, financing gaps, and limited inclusion of social actors in planning and implementation processes.

The electrification of public transport should be viewed not only as a technological upgrade but as a systemic transformation requiring collaborative governance, integrated policies, and a sustainability-oriented vision that balances environmental, economic, and social dimensions. In this regard, the perspectives gathered in this study offer critical input for designing more inclusive and context-sensitive strategies.

While the analysis focuses on Mexico City, many of the findings and proposals are relevant to other Latin American urban contexts undergoing similar transitions. However, the replication of strategies must be accompanied by contextual adaptation and comparative research.

From these findings, and to advance toward a more sustainable and inclusive transport model, the following recommendations are proposed:

- Develop a comprehensive regulatory framework to govern electric mobility systems' operation, financing, and interoperability, with differentiated provisions for the public transport sector.

- Strengthen the charging infrastructure and enhance the technical-operational capacities of electric fleets through strategic investments and specialised workforce training.
- Design public policies with a strong social and gender lens, ensuring active citizen engagement and the incorporation of women at all levels of the transport system.
- To lower the initial transition costs, promote innovative financing models, including public-private partnerships and access to international climate and development funds.
- Link electromobility with renewable energy generation to maximise environmental benefits while advancing innovative grid systems and sustainable energy planning.
- Foster inclusive, multi-stakeholder dialogue spaces and inter-institutional learning platforms – such as the roundtable featured in this study – to support informed, participatory, and coordinated decision-making.

These recommendations provide a roadmap for sustainable, inclusive, and forward-looking public transport electrification in Mexico City. They highlight the need for long-term vision, cross-sectoral collaboration, and innovation in governance and financing to ensure that the transition to electromobility catalyses broader urban and environmental transformation.

## 7 Future lines of research

Based on the findings of this study and the structural challenges identified in the implementation of electromobility, the following lines of future research are proposed to deepen the analysis and inform the development of effective and inclusive public policies in Latin American urban contexts:

1. Comprehensive environmental impact assessment of electromobility. Future research should evaluate the entire life cycle of electric vehicles, including raw material extraction, manufacturing, energy consumption, and end-of-life disposal. Comparative analyses between technologies, transport models, and energy sources – particularly renewable energy – are needed to assess the net environmental benefits and guide sustainable decision-making.
2. Circular economy and sustainable supply chains. The transition to electromobility demands reconfiguring supply chains, especially regarding battery production, reuse, and recycling. Research on circular economy models that enhance the durability, recyclability, and traceability of critical materials such as lithium and cobalt is needed. It also includes the design of fair, transparent, and resilient value chains with lower environmental footprints.
3. Collaborative governance and inter-institutional coordination. Advancing electromobility requires integrated governance models involving governments, transport operators, the private sector, and civil society. Future studies should explore mechanisms for inter-institutional coordination, participatory decision-making, and adaptive governance that enable scalable, transparent, and effective

policy implementation. The Five-INs framework (Initiative, Investment, Incentive, Information, and Innovation) proposed by Thakore et al. (2015) offers a valuable lens through which to evaluate governance conditions that promote systemic transitions.

4 Social inclusion and gender-sensitive approaches in sustainable mobility. Ensuring equitable access to the benefits of electromobility is essential for a just transition. Research should explore integrating gender perspectives, citizen participation, and territorial justice in electric transport systems' planning, regulation, and operation. Special attention should be given to strengthening the role of women across all dimensions of the sector – from governance to technology development.

5 Innovative financing instruments for electromobility. The high upfront costs of electrification remain a barrier to adoption. Future research should examine the design and impact of financing mechanisms such as public-private partnerships, green funds, sustainable bonds, operational leasing, and pay-as-you-go models. Täuscher and Chafac (2016) emphasise the value of scenario-based business model simulation in evaluating such schemes under uncertainty and identifying lock-in effects and economies of scale in multisectoral adoption.

6 Coevolutionary systems and sustainability transitions, Yolles (2018) suggests that sustainability is better understood through a coevolutionary systems lens, where institutional, environmental, economic, and social subsystems adapt in interaction. Research could explore how electromobility governance and policy design account for these interdependencies, including developing systemic indicators that reflect joint evolution, not isolated performance.

Together, these lines of inquiry can inform a robust research agenda that supports the development of inclusive, efficient, and environmentally sound mobility systems. Their exploration is critical for guiding policy decisions, accelerating innovation, and advancing a just and sustainable energy transition in Latin American cities.

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## Conflicts of interest

The authors declare no conflict of interest.

## Informed consent statement

All participants gave written informed consent, and their anonymised data was used exclusively for research per ethical guidelines.

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