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Research Article

Core components for a new era of electromobility using grounded theory: insights from Brazilian experts

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Abstract

Paper aims: This study analyzes the key factors shaping electromobility (EM) in Brazil to guide the development of effective regional adoption strategies. Addressing the gap in understanding the specific perceptions and representations of EM solutions among the Brazilian population, this research validates a novel framework of the main factors influencing EM in Brazil by applying Grounded Theory.

Originality: This research offers a unique framework integrating expert interviews and a literature review, providing a comprehensive perspective on the factors influencing EM.

Research method: 61 experts provided insights through interviews. Grounded theory methodology, including constant comparison and coding procedures, was employed for analysis.

Main findings: The study presents a novel EM framework highlighting factors such as Government Actions, Technology, Energy Matrix and Environment, Productive Chain, and Cost. It suggests strategies like tax incentives and innovation promotion to drive EM adoption.

Implications for theory and practice: Integrating Grounded Theory with a literature review enriches the theoretical understanding of EM, offering practical insights for driving adoption. The study emphasizes the importance of policy development, innovation investment, infrastructure planning, consumer awareness, and government guidance in successfully implementing EM in Brazil.

Keywords

Electric mobility. Grounded theory. Brazil. Government actions. Technology.

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1. Introduction

Brazil is one of the ten largest vehicle producers in the world and the biggest consumer of Energy in South America (Sousa & Castañeda-Ayarza, 2022). Cargo and passenger transport consumed 31.2% of the nation's energy in 2020 (Brasil, 2020). Any change in this sector significantly impacts the economy and the environment (Carvalho et al., 2020). Electromobility (EM) addresses all wheeled transport issues with battery-powered electric vehicles (EV), including technological, infrastructural, legislative, and economic models (Jaworski, 2018). Moreover, it can reduce the greenhouse gases (GHGs) emitted from renewable electricity generation. In 2015, Brazil submitted its Intended Nationally Determined Contribution to the Conference of the Parties to the UNFCCC (COP21). It consisted of an absolute mitigation target for the entire economy, and Brazilian GHG emissions were limited to 1.3 GtCO2e in 2025 and 1.2 GtCO2e in 2030, representing a reduction of 37% and 43% compared to 2005 (2.1 GtCO2e) (Grottera et al., 2022).

Electrification of mobility offers numerous advantages, particularly in emerging economies, where the reduction in oil dependency and environmental benefits are pressing needs (Sierzchula et al., 2014). Electric mobility, represented through various EV types, consumes less energy and emits no tailpipe GHG (Faria et al., 2014). Among EV options, Battery Electric Vehicles (BEVs) have been praised for their energy-efficient systems compared to internal combustion engine vehicles (ICEVs). However, research specific to EV adoption in emerging economies remains limited, especially regarding which EV types—electric four-wheelers (E4Ws), electric two-wheelers (E2Ws), or hybrid electric vehicles (HEVs)—are best suited for these markets (Deka et al., 2023; Porfiriev et al., 2020; Wu et al., 2021). Given the unique challenges and demands within emerging economies, Rajper & Albrecht (2020) explore the barriers and the opportunities in adopting these EV types. By examining the forces that promote EV adoption, such as emissions reduction, energy efficiency, fuel savings, and low operational costs, alongside the challenges—high purchase prices, limited range, and charging infrastructure constraints—this analysis aims to provide targeted insights into the optimal pathways for EV integration in emerging economies.

The Brazilian government's adoption of the Green Mobility and Innovation Program (MOVER) marks a pivotal moment in the country's automotive sector, building upon the foundations laid by the former Rota 2030 Program (Brasil, 2023). Spearheaded by a Provisional Measure signed by the Brazilian President in December 2023, MOVER, overseen by the Ministry of Development, Industry, Commerce, and Services (MDIC), is designed to advance sustainability and innovation within the industry. One of its key objectives is to incentivize investments in energy efficiency while implementing stricter standards for recycling and carbon emissions reduction. Notably, MOVER introduces a groundbreaking approach by assessing emissions "from well to wheel," encompassing the entire lifecycle of vehicles and their energy sources. Additionally, the program introduces the concept of "IPI Verde," a production taxation mechanism that favors vehicles with lower emissions, thereby promoting decarbonization and the development of cleaner technologies. Through significant tax incentives and the establishment of the National Industrial and Technological Development Fund (FNDIT), MOVER not only aims to foster research and development within the automotive sector but also seeks to attract strategic investments to Brazil, solidifying its position as a global leader in innovation and sustainable mobility. By offering vital insights into the critical elements of the Brazilian transition to electromobility and considering the similarity among the emerging country's challenges for electromobility introduction, even when taking the Chinese case into account, this article provides valuable perspectives that can guide policy design and implementation for low carbon mobility and transportation in emerging economies. Many works have investigated various incentives and barriers to the global spread of EM (Adnan et al., 2018; Biresselioglu et al., 2018; Buranelli de Oliveira et al., 2022; Consoni et al., 2018; Curtale et al., 2021; Dupont et al., 2019; Haustein & Jensen, 2018; Simsekoglu & Nayum, 2019; Sovacool et al., 2019a). According to Buranelli de Oliveira et al. (2022), the following are the most common limiting factors of using EVs: (i) substantially higher price of EVs compared with internal combustion engine (ICE) vehicles (Biresselioglu et al., 2018; Degirmenci & Breitner, 2017), (ii) insufficient maximum mileage for a single charge (Biresselioglu et al., 2018; Degirmenci & Breitner, 2017), (iii) battery and vehicle maintenance concerns, (iv) poor provision of public charging stations (Haustein & Jensen, 2018; She et al., 2017), (v) lack of trust and concerns about technical and operational constraints (Biresselioglu et al., 2018; Graham-Rowe et al., 2012), and (vi) little consumer interest in EVs due to lack of information (Egbue & Long, 2012; Krause et al., 2013). Authors such as Barbalho et al. (2018) states EVs as a disruptive technology, and consequently its introduction suffer influence of consumer behavior in regards to new technologies (Christensen, 2012). Dupont et al. (2019) examined the factors influencing how social groups view the new technology of EVs and provided factors regarding their prospective acceptance, encouraging widespread adoption.

The findings of Dupont et al. (2019), Tilman et al. (2009) and Wang & Wells (2020) reveal practical techniques for government departments, including the publication of relevant policies and targeting of specific consumer groups. Literature also provides the following motivating factors: (i) environmental advantages (Helmers & Marx, 2012); (ii) economic benefits, including lower operational costs (Adnan et al., 2018; Schuitema et al., 2013); and (iii) government measures, including fiscal incentives, subsidies, and reductions (Lebeau et al., 2012; Simsekoglu & Nayum, 2019).

Buranelli de Oliveira et al. (2022) founds that most (89.1%) of Brazilian consumers express interest in purchasing EVs, provided they are priced between USD 5,500 and USD 13,000. However, EVs typically have higher price tags, challenging widespread adoption. The total sales of EVs in 2023, as reported by the National Association of Motor Vehicle Manufacturers (Associação Nacional dos Fabricantes de Veículos Automotores, 2023), surged by 78% (93.908 licensed vehicles) compared to the previous year, indicating a significant uptick in adoption despite the recent increase in import tariffs on electric or hybrid vehicles effective January 1st, 2024. Therefore, it is imperative to identify the motivations and barriers influencing the diffusion of EVs and to comprehend the transition process using a new analytical framework.

This article addresses a significant gap in the literature on electromobility (EM), considering the contexts in emerging and new-emerging economies such as Thailand, Indonesia, and Mexico by examining how EM is perceived and represented by diverse stakeholders in the country to create an understandable framework for guiding policymakers. Existing EM research has primarily focused on technical, economic, and environmental aspects within global or broadly regional frameworks, leaving a lack of detailed insights specific to an emerging country's social, cultural, and economic landscape. Using grounded theory (GT) methodology (Glaser & Strauss, 1967), the study explores the unique perceptions, challenges, and expectations surrounding EM in Brazil, presenting a perspective often underrepresented in current literature.

The findings contribute with a validated framework for understanding Brazil-specific factors influencing EM adoption, enhancing the strategic knowledge base for policymakers and industry leaders. Moreover, these insights offer valuable guidance for Brazil and other emerging countries as they develop locally relevant strategies to foster EM adoption, bridging the gap between global EM insights and tailored actionable strategies. To achieve this aim, the study begins with a comprehensive review of existing studies on EM, highlighting gaps and identifying key factors previously unexplored in the Brazilian context. Insights are then gathered through interviews with 61 experts in the field, ensuring a diverse and representative sample of opinions and experiences related to EM in Brazil. Using the GT methodology, we systematically code and analyze interview data, identifying 28 statements that shape EM perceptions and adoption. The proposed framework is validated against the dataset to reflect accurately the multifaceted factors influencing EM in Brazil. We then compare our findings with a broad set of open-access articles and reviews from the Scopus database, published between 2016 and July 2021, to contextualize our results within the existing body of knowledge. Finally, we discuss the implications of our findings for policymakers, industry stakeholders, and researchers, offering targeted strategies for promoting EM adoption, such as tax incentives, innovation promotion, and infrastructure development.

This introduction presents a quick overview of the topic and its importance, and it is followed by the methodology that justifies the choice of the GT method used in the study. Further, this method's possibility for building analytical categories from data is described.

2. Materials and methods

GT is a reality-modeling research method (Glaser & Strauss, 1967). We adopted GT in this work because framework analysis is a qualitative method suitable for practical policy research (Srivastava & Thomson, 2009). Also, Ahmed et al. (2023) justify GT's effectiveness in providing in-depth insights into the complex dynamics and stakeholder relationships involved in regional development projects like the Orange Line Metro Train in Lahore. Data collection, including interviews, follows the study area and topic selection. For this, semi-structured interviews outperformed focus groups, according to Horváth & Szabó (2019). Once captured, the data are analyzed using a constant comparison method, coding procedures, and theoretical sampling. Subsequently, theories are generated using interpretive procedures before being finally written and presented (Petrini & Pozzebon, 2009).

GT has the following methodological characteristics: (1) theoretical sampling, (2) constant comparative data analysis, (3) elaboration of memos, and (4) difference between substantive and formal theories. Theoretical sampling is the collection of data to examine places, people, or events to identify changes between ideas and diversify categories and their features and dimensions to meet the needs of research development (Santos et al., 2019).

Qualitative framework analysis is helpful for policy research (Srivastava & Thomson, 2009). Qualitative methods, including GT, have gained popularity due to their ability to interpret complexity and provide detailed insights into various phenomena (Paget et al., 2010). Researchers have employed GT across diverse fields, such as medical research (Devlin et al., 2022), spatial planning (Lovrić & Lovrić, 2018), and industrial analysis (Li et al., 2019), highlighting its versatility and effectiveness in generating context-based descriptions of societal phenomena. Our adoption of GT in this paper is grounded in its suitability for practical policy research, as emphasized by Srivastava et al. (2022) and justified by Ahmed et al. (2023) in their study on regional development projects.

Hence, in this study, we used GT, a general comparative analysis method, and a collection of methods that may systematically generate a theory from data (Tarozzi, 2011). Figure 1 explains how the GT methodology was used in this work.

The coding approach revealed six fundamental aspects defining the Brazilian EM energy paradox. Comparisons with prior studies revealed unidentified items and findings (Horváth & Szabó, 2019).

3. Results and discussion

3.1. Initial coding

Between March 6, 2020, and May 18, 2020, we interviewed 61 EM specialists in semistructured interviews. 56% (34) of the respondents were from the private sector, 16% (10) were academics, and 28% (17) were from the government. The interviewees were asked to suggest 2–5 contacts under a snowball framework for the subsequent interviews (Baldin & Munhoz, 2011; Frate et al., 2019). The GT's "open coding" method was used within Atlas Ti Software to summarize the 856 different opinions into 28 statements (Table 1) with brief descriptions (Strauss & Corbin, 1998).

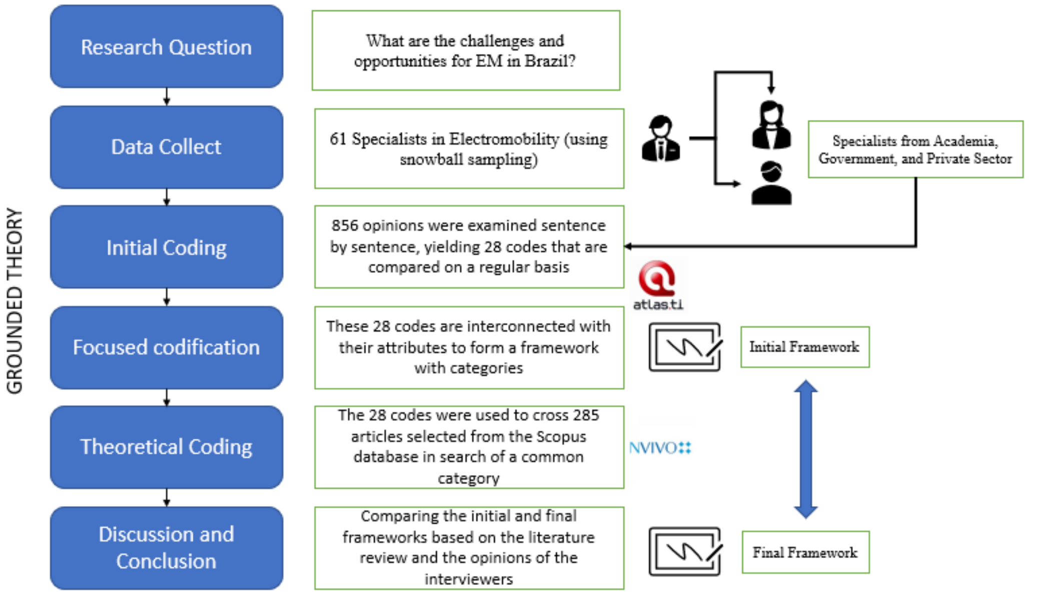

Figure 1. Visual representation of the grounded theory (GT) methodology.

Table 1. Initial research coding.

Item	Statements	Number of Opinions	Contribution to the Total Number of Opinions (%)
1	Investment (cost) of EVs as a challenge	70	8.18
2	National Productive Chain threatened	62	7.24
3	Environmental concern as an opportunity	59	6.89
4	Hybridization as an early stage of EM	51	5.96
5	Insufficient regulations/laws/standards	47	5.49
6	Charging station infrastructure is a challenge	45	5.26
7	Electric batteries are a challenge	43	5.02
8	The automobile production chain industry is an opportunity	39	4.56
9	Government tax incentives needed to boost EM	38	4.44
10	Technological development as an opportunity	37	4.32
11	Ambiguous government policies compromising electrification	37	4.32
12	Challenges of Biofuels to EM	30	3.50
13	Energy matrix contribution toward EM	28	3.27
14	City/municipality offering opportunities to heavy vehicles	27	3.15
15	Energy and mechanical efficiencies associated with comfort as an opportunity	24	2.80
16	Qualification/education/training to require the requalification of market professionals.	22	2.57
17	Business models driving the electrification of public transport.	22	2.57
18	Fuel cell vehicles (FCEVs) as the future	22	2.57
19	Vehicle sharing culture helping EM	20	2.34
20	Massive Brazilian auto business as a potential market for EVs	19	2.22
21	EM as a challenge for electricity distribution	17	1.99
22	Heavy vehicles (buses and trucks) are a great opportunity	17	1.99
23	EM's contribution to health	16	1.87
24	The association/cooperation of Triple Helix is a challenge	15	1.75
25	Urban mobility is systemic	15	1.75
26	National mineral chain as an opportunity	14	1.64
27	High charging time (cultural change required)	12	1.40
28	Lightweight vehicles as an opportunity	8	0.93
		856	100.00

3.2. Focused codification

We offered an initial framework of codes interconnected with their properties, which generated factors using the 28 codes from the previous phase. Six emerging factors were proposed in this initial framework: environment, technology, cost, government actions, and energy matrix. Table 2 demonstrates the crossings of the 28 statements with each factor.

Table 2. Initial framework with the emerging factors.

Government Actions	Technology	Productive Chain	Environment	Energy Matrix	Cost
5	18	10	3	15	1
9	4	20	23	13	6
11	7	2	12	21	
22	27	8			
28		26			
14		24			
17		16			
25					
19					

3.3. Theoretical coding

Through Grounded Theory Methodology (GT), we aimed to validate the 28 statements from our 61 interviewees by cross-referencing them with scientific literature, thereby confirming the 6 identified factors.

A search was performed in the Scopus database using the keywords "electric vehicle*" and "mobility," where it was limited to "open access" articles and reviews between 2016 and July 9, 2021, a minimum period of five years. Then, 285 articles were obtained. NVivo assessed the registered document extract categories (Bonello & Meehan, 2019). Thus, the relationships between the factors and statements were highlighted as follows, where each factor is presented according to literature analyses.

3.4. Summarizing the main findings in scientific literature

We validated this framework (Table 2) by overlapping the bibliography with survey specialist statements. Next, we demonstrate that the statements correspond to the research factors in the literature.

3.4.1. Investment (cost) of EVs as a challenge

EVs are entering the automotive market, but they are still expensive, mainly due to the cost of the battery (Safari, 2018). Concerns about the electricity sector change will raise electricity prices (Safarzyńska & van den Bergh, 2018). Policies need to reduce the cost of capital of EVs to ensure better parity (Sovacool et al., 2019a). However, when comparing operational costs, EVs are about 37% less expensive than diesel cars and 60% less expensive than gasoline cars (Petrauskiene et al., 2020; Liu et al., 2021b) highlight that despite the high initial cost and weight of batteries limiting EV driving ranges, technological advances in electrochemical energy storage and electric powertrains have driven rapid deployment, with operating savings enabling recovery of the initial cost in as little as five years, particularly for EVs with driving ranges under 200 miles (321 km).

3.4.2. National Productive Chain threatened

The transport industry is integral to the European economy (Andaloro et al., 2016), prompting governments to combine direct bailout support for leading manufacturers with a series of policies (Wang & Wells, 2020). Pavlínek (2023) analyzes Eastern Europe's slower transition from internal combustion engine vehicle production to EVs. This shift is primarily driven by foreign firms, with Eastern Europe's reliance on low production costs threatening its position in European automotive value chains as the transition progresses.

3.4.3. Environmental concern as an opportunity

According to recent figures, CO_2 emissions from road transportation have increased (Balacco et al., 2021). A rising body of evidence suggests that present levels of motorized transportation negatively influence environmental quality (Plazier et al., 2017). So, several countries have set phase-out dates for internal combustion engine vehicles (ICE), and these measures are encouraging but insufficient given the rapid progression of climate change (Kastner et al., 2021). Circular value chains are standing on the main waves of a new economic-environmental paradigm (Buranelli de Oliveira et al., 2022), and food value chains have been approached with technological-based transformations to low-carbon systems, such as organic and agro-forestry production (Barreto et al., 2024; Ferrari et al., 2023).

3.4.4. Hybridization as an early stage of EM

Road transport accounts for 18% of total energy-related CO2 emissions worldwide (Pareschi et al., 2020), and HEV can reduce GHG emissions compared to ICE (Abdul-Manan et al., 2020). HEV adoption could be the first step toward the sustainability of transportation and electric energy systems (Carlucci et al., 2018). Sanguesa et al. (2021) highlights that HEVs are evaluated for their environmental impact, focusing on aspects like greenhouse gas emissions and the production and lifecycle of vehicles and batteries.

3.4.5. Insufficient regulations/laws/standards

BEVs have the advantage of lowering air and noise pollution and may significantly improve the current condition of automobile exhaust pollution (Zhang et al., 2019). Literature, such as Kowalska-Pyzalska et al. (2020) reports serious problems faced in the EV market, which include unsafe and unclear regulations that may prevent producers and buyers from entering the market.

3.4.6. Charging station infrastructure is a challenge

Establishing a load point ratio greater than one per ten Plug-in EVs (PiEV) can result in minimal improvements and significant expenses. At target levels above 25 PiEV per charge station, PiEV sales are relatively unaffected (Harrison & Thiel, 2017). However, charging EVs on the go may occur during the journey in large cities and change this ratio. In this context, charging infrastructure flexibility and appropriate decision-making to manage to charge is critical for the EV industry's success (Cao et al., 2018). However, to enable EV development and keep installation costs low, charging infrastructure must be installed in locations with high charging potential (Pagany et al., 2019). Also, there is a need to implement fast-charging infrastructure, especially on highways (Melliger et al., 2018). Mastoi et al. (2022) analyze the transition to EVs, emphasizing the need for robust charging infrastructure, including distributed energy generation, IT integration, and supportive government policies, while addressing challenges and future trends like renewable energy use and grid benefits.

3.4.7. Electric batteries as a challenge

Lithium traction batteries are a vital technology for EVs, and their manufacturing contributes to increasing these vehicles´ production emissions. Their performance can significantly affect the lifecycle GHG emissions of EVs (Ambrose & Kendall, 2016). Given the present learning rates of 9% and 15% for the price and electrification costs of the BEV, respectively, price estimates show no chance of equilibrium between BEV and ICE before 2040 (Safari, 2018). Liu et al. (2023) highlight the challenges posed by EV batteries, emphasizing the need for increased life cycle and reduced costs to provide large-scale storage capacity for renewable energy, as well as breakthroughs in grid operation and long-duration storage technologies.

3.4.8. The automobile production chain industry is an opportunity

OEM companies hesitated to shift their support to BEV research as most of their sunk spending is related to existing ICE technologies, and BEV investment was deemed "disruptive" (Berkeley et al., 2017). How traditional automakers respond to carbon and vehicle reduction targets can significantly influence the availability and affordability of innovations such as EVs (Sovacool et al., 2019b).

3.4.9. Government tax incentives are needed to boost EM

Subsidies would aid in the spread of EVs and the transition away from fossil fuels by lowering the cost of purchasing and operating them (Canals Casals & Amante García, 2016). Offering EV purchase subsidies before all technologies are accessible can lead to technology lock-in and prevent the long-term maturity of less developed technologies due to the dynamics of technology competition (Harrison & Thiel, 2017). Srivastava et al. (2022) emphasize the need for government tax incentives to boost EV market penetration, demonstrating through game-theoretical analysis that a mix of differential taxation and subsidies can maximize social welfare, manufacturer profit, government income, and consumer surplus.

3.4.10. Technological development as an opportunity

The work of Morlock & Sawodny (2018) presents a framework for an economical cruise. By 2030, autonomous vehicles are expected to come into play and are more likely to be electric and shared (van Mierlo et al., 2021). Reducing risks in future planning should lead to an accelerated diffusion of EVs into the market and intensified R&D activities (Wolf & Korzynietz, 2019). All vehicles will soon be required to be connected (V2V) as well as to the infrastructure (V2I) for a variety of purposes (Sanguesa et al., 2021).

3.4.11. Ambiguous government policies compromising electrification

Liu et al. (2021a) highlight China's successful adoption of EVs, driven by unambiguous government policies that include financial incentives and convenience measures, effectively promoting EV use in both public and private sectors. It should be clear that policymakers support the electrification of road transport for several reasons—to decrease urban noise pollution, mitigate transport-related CO2 emissions, and secure the energy supply for citizens' mobility (Weiss et al., 2020).

3.4.12. Challenges of Biofuels to EM

Dranka & Ferreira (2020) discuss the challenges of integrating biofuels and renewable energy in Brazil, highlighting the need for large-scale studies to assess the impacts of EVs on the energy system, including CO2 emissions and the role of renewable energy and biofuels in reducing those emissions. The blocking effects that sustain the biofuels industry can induce negative externalities in EVs. So, the interaction between industry, energy, transport regimes, and related institutions is crucial (Kotilainen et al., 2019). An example of a challenge is the Brazilian ethanol production program to reduce gasoline imports (Glensor & Muñoz, 2019).

3.4.13. Energy matrix contribution toward EM

EVs reduce pollution only if a high percentage of the electricity mix comes from renewable sources and if battery manufacturing is far from the vehicle's use region (Vidhi & Shrivastava, 2018). Only by combining the deployment of EVs with the diffusion of renewable energies in the power sector can the benefits be realized—these intertwined transitions challenge network integration (Safarzyńska & van den Bergh, 2018). Maldonado et al. (2024) present electric vehicle charging load profiles for Mexican cities and project a 2040 hourly load increase on the electric grid, finding that smart charging and policies like energy efficiency and demand response could reduce peak load by over 3 GW, mitigating grid stress.

3.4.14. City/Municipality offering opportunities to heavy vehicles

Some governments allow only EVs that do not pollute the air in the city center as part of a policy to reduce air pollution (Vidhi & Shrivastava, 2018). However, the efficiency of these new transport systems cannot be guaranteed in an ordinary city, as in practice, new problems have arisen related to energy distribution and traffic organization. Therefore, a 'smart city' approach can help achieve this vision (Aymen & Mahmoudi, 2019).

3.4.15. Energy and mechanical efficiency are associated with comfort as an opportunity

EVs are advantageous relative to ICE in terms of energy efficiency, energy security, lower costs/km, noise, and local air pollution (Morlock & Sawodny, 2018). Lashari et al. (2021) found that consumer perceptions of environmental and economic benefits are the strongest predictors of EV purchases, while technological concerns negatively impact purchase intentions, offering valuable insights.

3.4.16. Qualification/education/training to require the requalification of market professionals

Dupuis et al. (2024) emphasize the importance of reskilling workers in the automotive industry, using the German shift to EV production as a case study, and offer global recommendations for unions and policymakers to ensure a fair transition. Elias & Gitelman (2018) suggest that road safety education and training and improving existing infrastructure is the best path for using e-bikes.

3.4.17. Business models driving the electrification of public transport

The Transportation Master Plan Santiago (Chile) 2025, for example, intends to develop a coordinated project program that incorporates various approaches and institutions to achieve the following goals: efficiency, public transportation, equity, sustainability, and safety (Fernandez-Sanchez & Fernandez-Heredia, 2018). In Cansino et al. (2018), we have the mandatory use of EVs in taxis and other fleets, thinking on the Chilean case and the Spanish context.

3.4.18. Fuel cell vehicles (FCEV) are the future

Although they allow zero emissions, BEVs have relevant restrictions such as low autonomy and slow recharge time. These two problems can be overcome by considering FCEV (Fernandez-Sanchez & Fernandez-Heredia, 2018). Increasing the FCEV's usefulness by increasing the number of hydrogen filling stations due to subsidies leads to a more significant market share, assuming shares otherwise assigned to the BEV in the comparative scenarios (Harrison & Thiel, 2017). The study by Luca de Tena & Pregger (2018) illustrates that controlled charging and flexible hydrogen production infrastructure can help avoid peak demand and alleviate renewable energy restrictions, lowering system operating, generating, and expansion costs.

3.4.19. Vehicle sharing culture helping EM

One-way electrical car-sharing systems offer an eco-friendly option to facilitate urban mobility needs. However, its management presents operational challenges (Boyacı & Zografos, 2019). Nonetheless, shared autonomous vehicles are the next significant evolution in urban mobility (Jung & Koo, 2018). Wang et al. (2021) propose a two-stage planning method for charging infrastructure to support large-scale sharing electric vehicles (SEVs) businesses, balancing SEV operators' economic needs with users' convenience, ultimately aiding electromobility's advancement.

3.4.20. Massive Brazilian auto business as a potential market for EVs

Several studies have examined the future penetration of the EV market, with short—and long-term forecasts varying widely. The International Energy Agency (IEA) predicts that just 9% of the global light vehicle fleet will be electric in 2030 and 40% in 2050 (Harrison & Thiel, 2017). Some papers report that the EV share is growing marginally (Berkeley et al., 2017; Bigerna & Micheli, 2018; Costa et al., 2020; Sharma & Jain, 2020).

3.4.21. EM is a challenge for electricity distribution

According to López-Sánchez et al. (2020), a typical distribution network can handle 40% penetration of EVs without boosting capacity, even when night charging is slow. With the high anticipated penetration of distributed power and EV resources, increasing confidence in real-time monitoring and control is necessary for the power grid to deal with these unprecedented levels of load uncertainty (Mohamed, 2019). The smart grid is one of the most promising infrastructures for improving access to electricity (Rodríguez-Molina et al., 2020). An optimal vehicle-to-grid (V2G) and grid-to-vehicle (G2V) control mechanism should reduce the negative impact of EVs on the network, minimizing the charging cost (Bagheri Tookanlou et al., 2021). The rapid growth of EVs is likely to degrade voltage profiles and overburden distribution networks. Coordinating the charging schedules could be viable (Sun et al., 2020).

3.4.22. Heavy vehicles (buses and trucks) are a great opportunity

In Bi et al. (2016), electric buses with wireless charging were better than diesel buses in terms of carbon emissions. In this way, commercial vehicle fleets are critical to EVs' widespread adoption and have a favorable environmental impact (Globisch et al., 2018). This literature suggests that providing direct financing to operators or local governments could stimulate the electrification of urban buses. Furthermore, EVs could work the routes if they are tendered (Glensor & Muñoz, 2019). Rodrigues & Seixas (2022) analyze the global transition to battery-electric buses (BEBs) in urban transport, highlighting barriers such as technology, finance, and institutional issues and providing recommendations like new financing protocols and support for innovation policies to aid successful BEB adoption.

3.4.23. EM's contribution to health

Vehicle emissions from ICE are one of the most significant contributors to air pollutants (Vidhi & Shrivastava, 2018). The production of vehicular flue gases, including carbon monoxide, hydrocarbon, sulfur dioxide, nitrogen oxides, and particulate matter, can degrade public health (Rith et al., 2020). Replacing today's ICEs with EVs in public fleets can profoundly impact air quality in cities (Fraile-Ardanuy et al., 2018).

3.4.24. The association/cooperation of Triple Helix is a challenge

The German automobile industry hesitates to disrupt its long-standing business model and has thus far avoided significant changes to electromobility. Furthermore, unions are one of the factors impeding its transition (Richter & Haas, 2020). Automakers, supply chain firms, infrastructure providers, government, financial resource providers, and car drivers should all be involved in the shift to greener autos (Berkeley et al., 2017). Marinelli et al. (2020) compile insights and outcomes from multiple grid integration demonstration projects involving EVs, highlighting trends and specific project details within the European Energy Research Alliance Joint Program on Smart Grids, demonstrating the challenges of the triplex helix relations as demonstrated on other disruptive technology value chains (Barbalho et al., 2018).

3.4.25. Urban mobility is systemic

Mobility plays a fundamental role in the development of social and economic activities. Economic analyses have shown a strict correlation between economic development and gross domestic product, mobility demand, freight transport, and environmental degradation (Fraile-Ardanuy et al., 2018). Thus, Mobility as a service (MaaS) is defined as a transition from a paradigm under which mobility functionality is accessed through purchasing a product to a paradigm where mobility functionality results from service moving users from one location to another (Richter & Haas, 2020).

3.4.26. National minerals chain as an opportunity

Lithium mining will expand as demand for the metal rises, as only about 1% of lithium can be recycled. By 2050, roughly 40% of lithium will be recyclable (Vidhi & Shrivastava, 2018). In the scenario analyzed by Wolf & Korzynietz (2019), global cobalt demand for EV batteries is expected to reach around 80% of total world cobalt mine production by 2030, implying that manufacturers may need to transition to new battery chemistries, such as Lithium Iron Phosphate (Nitta et al., 2015). Lithium mining and battery manufacturing industries must mature to ensure cheap battery supply (Vidhi & Shrivastava, 2018).

3.4.27. High charging time (cultural change required)

Due to the battery's limited electricity, EV drivers may experience inconvenience during an extended charging wait time. Unlike plug-in loading technology, Cao et al. (2018) investigated battery-switching technology to improve the comfort of EV drivers. There are still unresolved concerns with the current generation of EVs, such as quick charging, range, infrastructure, and network load (Bigerna & Micheli, 2018). At the 350-kW recharge station, the recharge time would be close to the gasoline refueling time: about 7 min. However, it should be noted that charging time also depends on the vehicle battery (Hsieh et al., 2019).

3.4.28. Lightweight vehicles as an opportunity

E-bikes and Micro Mobility are individual modes of transportation that reduce traffic while achieving zero emissions and making it easier for individuals to go about (Balacco et al., 2021). In addition, using e-bikes brings direct health benefits to users and reduces harmful emissions (Riedner et al., 2019). For those for whom conventional riding is not a viable choice, electrically assisted cycling, or e-biking, presents itself as an appealing alternative to motorized commuting. Because it competes directly with automobile use, attempts to boost e-bike use must target car users (Plazier et al., 2017).

3.4.29. Summary

As demonstrated above, the scientific bibliography could link elements and statements and meaningfully fill significant crossings (Frate et al., 2019).

The energy transition in transport requires a comprehensive government strategy, including policies and regulations that encourage low-carbon transport options through subsidies, tax credits, and exemptions. Investments in EV charging infrastructure, bike lanes, pedestrian safety, and fuel efficiency standards are crucial. Promotion of alternative fuels like biofuels and hydrogen, alongside public transport improvements, is necessary. Governments should also educate the public on low-carbon transport benefits.

Technological advances play a vital role in this transition. Improved battery technology will extend EV ranges and reduce charging times. Significant investments in EV charging infrastructure and the development of biofuels and hydrogen fuel cells will help reduce emissions. AI and IoT can optimize transportation systems, and once connected, autonomous vehicles can improve energy efficiency.

The shift towards EVs benefits the automobile production chain by reducing reliance on fossil fuels, simplifying the production process, and emphasizing sustainable sourcing of materials like lithium, cobalt, and nickel. EV adoption also reduces urban pollution, contributing to better public health.

An energy matrix can aid the transition by comparing energy sources based on environmental impact, availability, and cost. However, challenges remain, such as the high cost of new lithium battery technologies and the need for a widespread charging station infrastructure.

4. Concluding remarks and framework

This paper provides insights into Brazil's critical elements for transitioning to EM. We employed GT and a literature review, intersecting these with coded insights from 61 experts´ interviews. Initially, we classified 856 opinions from these respondents—comprising government, academia, and the private sector—into 28 statements using Atlas Ti software, all in response to our research question about the opportunities and challenges facing EM in Brazil. To strengthen our analysis, we contextualize the benefits and challenges of EM within the broader landscape of emerging economies, according to our literature research protocol. This emphasizes the unique opportunities and barriers to EV adoption in these regions, including Brazil, thus laying a foundation for understanding the shared and specific factors influencing EV integration in similar economic contexts. This enhancement aligns our findings more closely with the broader emerging market framework.

This study provides some insights. While significant focus was given to government actions, technological advancement, and the clean energy matrix, the dynamics of consumer and organizational markets play an essential role in shaping EV adoption and deserve further emphasis. The diffusion of green products, like EVs, across both markets suggests a reciprocal influence where public transportation market adoption can positively affect consumer perceptions. Findings from existing research (Zhang et al., 2023) indicate that consumers tend to favor companies engaged in both public and consumer EV markets, associating higher functional and expressive value with brands active in public transportation. However, consumer preference can shift when they comparatively evaluate the companies, with a bias toward those specializing solely in personal cars. These behavioral dynamics underline the importance of nuanced market strategies that address consumer and organizational market interactions in EM landscapes. As the framework evolves, future research should investigate how organizational entry into public markets impacts consumer behavior, thus enriching EM adoption strategies to the contexts of emerging economies.

Exploring the literature review of the Scopus database with the selection of 285 articles and using the NVivo software, we sought the relationship between the 28 statements and the six factors initially established. Next, we highlight the elements of the conceptual confrontation taken from the bibliographic review that manage to explain the 28 statements. With this intersection, we explain the six emerging factors of the framework.

The desired results of the technology domain, clean energy matrix, and EV market can be achieved by influencing several factors, including (Figure 2):

1. Government Actions: Governments, as agents and together with academia and the private sector, can influence the development and adoption of clean energy technologies and EVs through policies such as tax incentives, subsidies, and regulations that encourage their use. Zhang et al. (2014) review policies from various countries to stimulate EV markets and highlight effective strategies each nation can adopt for specific needs;

2. Technology: Continued investment in research and development can lead to technological advancements that make clean energy more efficient and cost-effective. Private investment in the EV market can also help to drive innovation and growth. LaMonaca & Ryan (2022) examine whether EV charging infrastructure should be treated as a public good or private asset, considering optimal charger locations, deployment models, and supportive policy frameworks;

3. Energy Matrix and Environment: To establish a clean energy matrix, it is essential to transition from traditional fossil fuels to cleaner alternatives. This shift necessitates substantial investments in renewable energy infrastructure, including constructing wind and solar farms and enhancing the electrical grid to accommodate these new power sources. Environmental improvement is also critical for achieving these objectives, particularly in reducing GHG emissions and air pollution. According to Strielkowski et al. (2021), the electrical power sector is vital for countries' economic growth and development worldwide, with global demand for electricity rising in both developed and emerging economies. The commitment to decarbonization—replacing fossil fuels with renewable energy sources (RES) and electrifying transport and heating to combat climate change—will significantly increase electricity consumption globally. Therefore, the electric power sector must integrate sustainable development principles. Recent events, such as the European gas crisis stemming from the rapid deployment of renewables, underscore the need for careful analysis and prevention of such challenges;

4. Productive Chain and Cost: Consumer demand for clean energy and more affordable electric vehicles (EVs) can stimulate market growth and foster additional investment and innovation. This is underscored by the study conducted by Patil (2018), which explores the technological advancements, market trends, and environmental impacts of EVs. Through a thorough analysis of current research and industry reports, the study identifies several key findings: advancements in battery technology, charging infrastructure, and autonomous driving have enhanced the efficiency, affordability, and practicality of EVs.

Engaging various stakeholders—consumers, businesses, government entities, and researchers- is essential to facilitate EV adoption in Brazil and other emerging markets, as each group plays a pivotal role in shaping market dynamics. Strengthening interactions between consumer and organizational markets can significantly influence EV uptake, though the framework proposed in Figure 2 overlooks customer behavior as a critical factor. This omission is notable, especially considering global trends like China's strategic push toward new energy vehicles (NEVs) to address energy conservation pressures and air quality concerns (Ouyang et al., 2018). Future studies can address this gap by incorporating consumer behavior analysis, following approaches like those in Costa et al. (2007), emphasizing that consumer perceptions of service performance are typically based on subjective judgments across multiple criteria. The overall result of our methodological approach allows us to understand that cost and environmental appeals are the main reasons for the consumer's decision on whether electric vehicles are emerging as a mobility option. Figure 2 represents a hypothetical framework from our research and can be used in other investigation protocols, such as statistical surveys or structural equation modeling, to deepen the understanding of EV adoption in emerging countries.

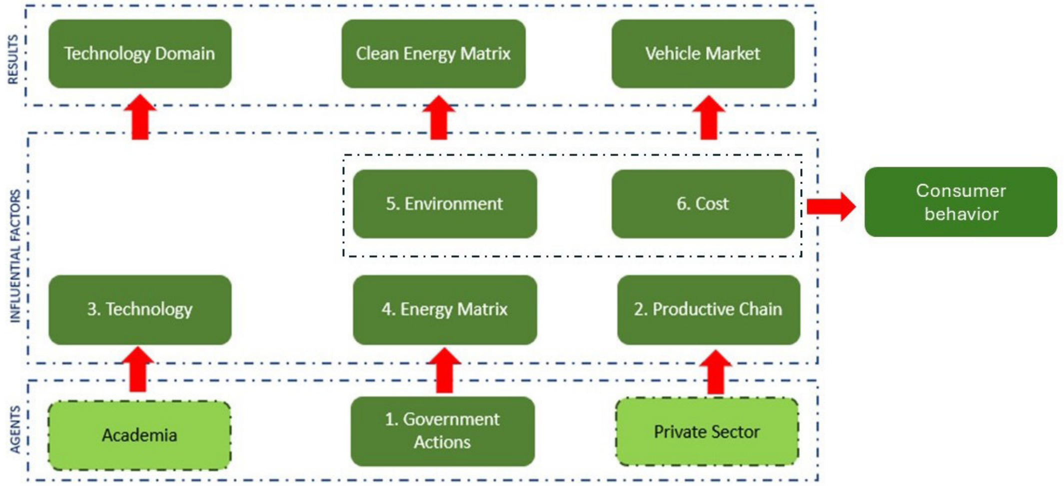

Figure 2. Framework to overcome challenges and explore opportunities.

The study acknowledges several limitations despite reaching the tentative framework presented for future research. Brazil's lack of firm government actions and regulations discourages necessary investments, highlighting the need for effective R&D investment strategies. The current Brazilian government's role in the EM ecosystem, exemplified by the MOVER program, is crucial for maintaining global competitiveness in the automobile industry. Promoting tax incentives is vital during this developmental phase, with a gradual reduction as consumer adoption increases. Studies addressing the possible impacts and the best design for these incentive programs can also deepen the adoption of EVs in emerging countries.

Brazil's relatively clean energy grid is considered an asset. Programs like Proalcool and policies like RenovaBio emphasize the strategic importance of biofuels, including ethanol, biodiesel, biomethane, biokerosene, and second-generation fuels. R&D incentives should focus on emerging technologies like FCEVs, leveraging Brazil's potential for green hydrogen production. Similar approaches have been implemented in various emerging countries, and research can also be carried out to evaluate the impact of these programs and design them accordingly to align them with the EM efforts taken by the world automotive industry.

The study's findings are limited to the perspectives of the experts interviewed, and future research should explore each identified element in greater depth. This work aims to outline the critical aspects of EM, identifying both obstacles and opportunities for a prospective EM-based electrical transformation program in Brazil and South America. Specifically, this study aims to analyze the key factors shaping EM in Brazil to guide the development of effective regional adoption strategies. By addressing the gap in understanding the specific perceptions and representations of EM solutions among Brazilian experts, this research validates a novel framework of the main factors influencing EM in Brazil through applying GT. Future research can apply our results to a sample of the whole Brazilian population to understand their general view in regards to electromobility once our results present costs and environmental issues as the main drivers for consumer behavior regarding electric vehicles.

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