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«Electric Mobility Investments: Insights from Power-Transport Coupling from Developing Countries»

by

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Electric mobility investments: insights from power-transport coupling from developing countries.

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Abstract

Electric mobility seems promising for the decarbonisation of the power and transport sectors. Nonetheless, making investment decisions on electric mobility in developing countries remains topical in policy and academic debate. This paper contributes to the transport and power sector coupling debate to understand investment decision-making on electric mobility. We propose a framework and identify developing countries that could be considered for private-sector investment in electric mobility. We validate our framework with case studies on investments in electric mobility in China, Brazil, India, Colombia, Türkiye and Chile. We argue that developing countries with wholesale power markets, and wholesale and retail power markets could attract investment in electric mobility, albeit with a proliferation of low total cost of ownership electric mobility investment options such as two and three-electric wheelers and investments such as electric buses perceived to have notable contributions to achieving environmental/climate objectives. Thus, we argue that our framework and analyses could be helpful for policymakers and stakeholders in the power and transport sectors to identify and select developing countries for private sector-led electric mobility investment.

Keywords: electric mobility, electric utilities, investment, decarbonisation, digitalisation, developing countries.

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1. Introduction

The ongoing energy transition aims to transform the global power sector from fossil-based to low-carbon resources to reduce emissions (Kola-Bezka, 2023). Thus, the contemporary landscape of power systems is experiencing a significant transformation, marked by the integration of distributed energy resources, energy storage systems, and electric mobility (Li et al., 2023). Electric mobility could offer the power sector a decentralised, clean power supply source, digitally connected, and flexible energy storage solutions. Moreover, the transport sector is a major consumer of energy resources and a primary contributor to greenhouse gas (GHG) emissions (Sæther, 2022). Approximately 20% of the total global CO_2 emissions come from the transport sector, and 71% of these CO_2 emissions are from road transportation (Gönül et al., 2021). In this context, electric mobility appears to be a promising solution for reducing emissions in the transport sector. Thus, many governments in developing countries have identified transport electrification as a promising strategy for transport sector decarbonisation (Briceno-Garmendia, 2022; Zhang and Hanaoka, 2021).

The transition towards electric mobility is critical and has global implications for meeting sustainable mobility objectives (Huang et al., 2021). For example, battery electric vehicles (BEV) offer a promising solution to reducing pollution from internal combustion engine vehicles due to their low lifecycle CO_2 emissions (Yuan et al., 2024); and increased prospects of contributing to reducing CO_2 emissions if the electricity they are powered with is generated from renewable and clean energy sources (Arora and Gargava, 2023; Santos and Smith, 2023). Therefore, electric mobility adoption (for example, EVs and two and three-wheelers) is growing with increasing policy support (IEA, 2024a; Li et al., 2024). Moreover, electric mobility and investment in new clean energy resources could play a role in energy communities by reducing carbon emissions of electric utilities, strengthening grid resilience and contributing to a sustainable energy transition (Abhyankar, 2023a; Velkovski et al., 2024b). For example, EVs could benefit from the power system's flexibility to integrate more renewable energies and contribute significantly to achieving climate objectives (Arora and Gargava, 2023).

The grid should be able to manage intermittent energy supply sources when electric mobility is integrated into it. In this context, digital technologies become essential. For example, digital technologies would facilitate matching power supply patterns and mobility demand to identify and optimise EV charging points (IRENA, 2019). With digitalisation, smart networks could make the power and transport sectors more efficient and cost-effective and meet user expectations with reduced costs (Bhatt and Singh, 2021). EV fleets could also provide power storage capacity to support decarbonisation. Integrating renewable energy sources in road transport could advance through transport electrification and contribute to flexibility in energy

systems (Rosa et al., 2023). For instance, using EVs as a flexibility resource through smart charging methods could reduce the need for investment in fossil-fuel power plants to intermittent renewable power generation and lower charging costs for consumers. Smart charging supported by digital technologies could also reduce peak power exchanges with the distribution grid, lower transmission and distribution losses and improve demand side flexibility (Velkovski et al. 2024).

It is worth noting that deploying electric mobility, which could increase power demand while decarbonising the power and transport sectors, and deploying digital technologies are challenging for developing countries. Electric utilities in developing countries face challenges such as high interest rates, scarce capital, and high currency risks, making the conditions for investment in decarbonisation and digital technologies challenging (Cunial, 2024; Papadis and Tsatsaronis, 2020). Developing countries also have high investment needs that could continue to increase with increasing power demand. Because of the interaction between the transport and power sectors, transport electrification should be done with the decarbonisation and digitalisation of the power sector (IRENA, 2019). Nonetheless, securing investments for electric mobility remains challenging in many developing countries. Prior research in the literature noted high investment costs, lack of grid power access, and lack of charging infrastructure as challenges to electric mobility investment and deployment in many developing countries. In this paper, we build upon the existing literature and attempt to answer the research question: How can electric mobility private sector investment be harnessed in the context of power and transport sector interaction in developing countries?

Building upon insight from the theoretical framework of the industrial organisation of electric utilities ex-post market reforms (Hunt, 2002), we extend the model to discuss the contemporary state of the electric utilities industrial model in developing countries, hypothesising the integration of electric mobility in the context of decarbonisation and digitalisation. Then, we conduct case study analyses of six developing countries (China, India, Brazil, Chile, Colombia, and Türkiye) with wholesale market power or wholesale and retail power markets to test our hypotheses. We selected these countries to provide a comprehensive overview of continental differences while addressing country-specific challenges. We provide insights on developing countries that are potential electric mobility investment destinations. Then, we offer insights and policy recommendations for electric mobility investment in developing countries.

We organise this paper as follows. Section 2 presents the materials and methods. Section 3 is the country case studies. Section 4 is the discussion. Section 5 is the conclusion and policy implications.

2. Materials and methods

In our previous work, Arowolo and Perez (2023), we review the literature on electric mobility investment in developing countries. The extant literature, such as (Dioha et al. 2022; Collett et al., 2021; Goel et al., 2021; Tuan et al., 2021; Mali et al., 2022; Draeck et al., 2021; Grutter and Kim, 2019; Ayetor et al., 2021; Rajper and Abrecht, 2028; Gomis et al., 2018) generally identified lack of grid power access, small grid size, charging infrastructure and high investment costs as challenges to electric mobility investment and deployment in many developing countries. Then, we proposed a framework to identify some developing countries for electric mobility investments. This paper builds upon the framework proposed in our previous work and extends our existing research with the case studies of China, India, Brazil, Chile, Türkiye and Columbia. We selected these countries to explore continental differences while providing insights into country-specific challenges and workable solutions.

2.1 Framework on the interaction between electric mobility and utilities

Arowolo and Perez (2023) and Arowolo and Perez (2024) describe the industrial organisation models of electric utilities and propose new ones.

2.1.1 Vertically integrated utility model

Electric utilities were vertically integrated utilities (VIU) under the government's control or strongly regulated in many countries before power market reform. The VIUs were responsible for generating, transmitting, distributing and retailing electricity to consumers. However, the state-controlled vertically integrated utilities suffered from low efficiency and poor service quality. Therefore, there was a demand for market-driven reforms. The steps in the standard electricity reform model include - privatisation of state-owned utilities, vertical separation of competitive segment from regulated segments, horizontal restructuring of the generation segment, horizontal integration of transmission and network operations, creation of voluntary public wholesale spot energy and operating reserve market institutions, the application of regulatory rules and supporting network institutions, retail tariff unbundling, retail competition, establishment of an independent regulator, and introducing efficient transition mechanisms (Arowolo and Perez, 2020).

2.1.2 Wholesale Electricity Market Model

Beginning in Chile in 1982, many countries have undertaken market-oriented power sector reforms. The primary objective of the reforms in developing countries is to unbundle the vertically integrated state-owned electric utilities to enhance their efficiency through market competition, attract private sector investment and improve service delivery (Timilsina et al., 2021; Ahmed and Bhatti, 2019). In this model, the electric utilities' generation, transmission

and distribution functions are unbundled, and competition is introduced among power generators. Distribution and transmission services offered by monopolies are often subject to regulatory supervision. The expected advantage of unbundling and privatisation is that the electric utilities could earn sufficient revenues with cost-reflective tariffs and access private sector investments. Therefore, many developing countries attempted to establish wholesale power markets (Rudnick and Velasquez, 2018).

2.1.3 Wholesale and retail electricity market model (Wholesale and retail)

In the wholesale and retail model, all the market actors have full access to the market. Consumers have the opportunity to procure their energy from competing retail suppliers instead of only the power distribution company (Sioshansi and Pfaffenberger, 2006). Nonetheless, with the availability of new technologies on the supply side (such as renewable energy and battery storage) and demand (such as electric vehicles) sides, there are more significant market design challenges. Introducing wholesale and retail competition[2] could also facilitate the entry of new, more efficient plants and market participants (ESMAP, 2022).

2.1.4 The Single-buyer Model

Many developing countries did not completely implement power market reforms due to the implementation challenges of the processes involved in the standard electricity reform model. These processes, such as creating competitive wholesale power markets, were challenging for developing countries. For example, there is a need for a sizable number of generation companies to facilitate competition and an absence of transmission bottlenecks that create market power (Rudnick and Velasquez, 2018) which was a challenging precondition for many developing countries to meet. Therefore, the so-called' single-buyer model', a hybrid model where government control and private ownership coexist emerged in the power markets emerged.

2.1.5 Peer-to-Peer innovation with electric mobility model

A peer-to-peer innovation with electric mobility is emerging in developed and developing countries. This innovation integrates renewable energy sources and digitally enabled communication technologies with new decentralised storage solutions (such as electric mobility and battery energy storage systems). Furthermore, the peer-to-peer innovation with electric mobility model includes new market actors such as aggregators and electric mobility manufacturers (Gomes et al., 2020).

Digital technology could enable bi-directional power flow and peer-to-peer energy trading among residential and commercial buildings and the distribution grid in this model. We

[2] Retail competition in this paper includes small and industrial/commercial customers.

hypothesise that the burgeoning peer-to-peer innovation with electric mobility model has more impact of digitalisation than the other industrial organisation models. For instance, peer-to-peer communication signals (digitalisation) can support power flow from EVs with a high level of decentralised or renewable power generation to facilitate decarbonisation.

We hypothesise that electric utilities in developing countries are gradually shifting from Models 1, 2, 3 and 4 to include features of peer-to-peer innovation with electric mobility model. We describe the transformation of the electric utilities industrial organisation as Model 1+, Model 2+, Model 3+ and Model 4+ (see Figure 1).

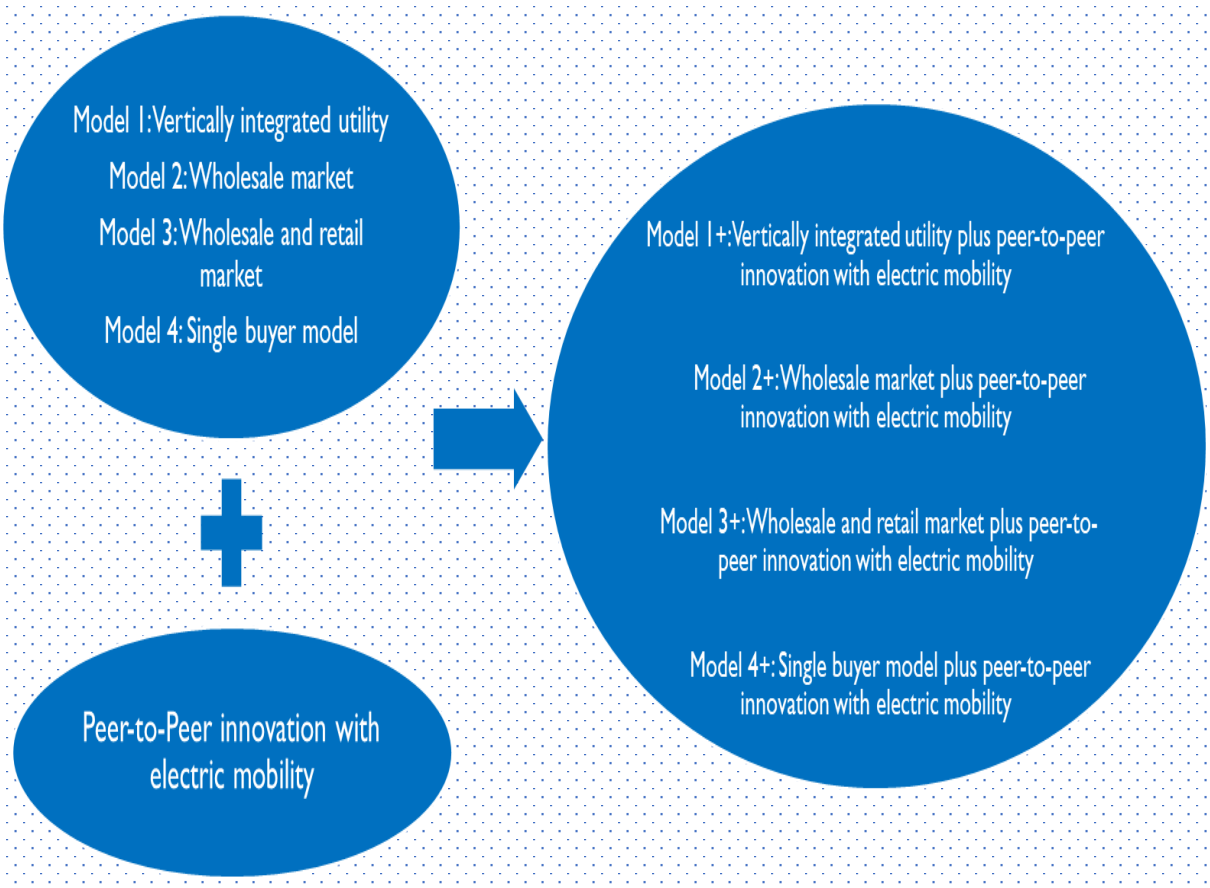

Figure 1: Utilities transformation by the peer-to-peer innovation with electric mobility

2.2 The proposed paradigm

Using the foregoing analysis as a springboard, we present our electric utilities' interaction with electric mobility industrial organisation framework to describe their transformation in the context of decarbonisation and digitalisation (see Table 1).

Electric Utilities Industrial Organisation model	Decarbonisation	Digitalisation
Full vertical integration + peer-to-peer innovation with electric mobility (Model 1+)	+	+
Single buyer + peer-to-peer innovation with electric mobility (Model 4+)	++	++
Wholesale market + peer-to-peer innovation with electric mobility (Model 2+)	+++	+++
Wholesale and retail market + peer-to-peer innovation with electric mobility (Model 3+)	+++	+++

Table 1: Electric mobility and electric utilities industrial organisation framework.

We hypothesise the relationship between our proposed electric utilities industrial organisation models and how each model could be impacted by digitalisation and decarbonisation (Table 1). Then, we identify and classify developing countries using the framework.

The plus sign depicts the increasing impact of decarbonisation and digitalisation on electric utilities from one plus (+) to three plus (+++) based on their industrial organisation model. This means that the impact of digitalisation and decarbonisation will increase as the level of power market reform plus peer-to-peer innovation with electric mobility increases. We hypothesise that the transformation of electric utilities with electric mobility caused by the impact of decarbonisation and digitalisation will be lowest in developing countries with vertically integrated utilities, that is, Model 1+ classification. Many Sub-Sahara Africa (SSA) countries are classified under either Models 1+ or Model 4+ category. For example, innovations such as vehicle-to-grid integration, peer-to-peer trading, the emergence of aggregator business models, the interrelationships among aggregators, distribution and transmission utilities, and EV owners do not presently constitute primary concerns of SSA electric utilities. Given that both EV ownership rates and charging infrastructure remain notably low, issues such as peer-to-peer energy trading and aggregator dynamics are not prominent contemporary issues of SSA electric utilities; rather, the topical issue appears to be investment in electricity access.

Developing countries with (Model 2+) and (Model 3+) are hypothesised to have the highest levels of the impact of decarbonisation and digitalisation. We hypothesise that the impact of digitalisation and decarbonisation will increase as a developing country moves from one model to another in the reform process.

Based on the insight from Table 1, we study the literature, notably the works of (Foster et al., 2017; Foster and Rana, 2020) from the World Bank and de Halleux et al. (2020) on the industrial organisation of electric utilities in most developing countries. Foster et al. (2017)

analysed power sector reforms in 88 developing countries and provided a country-specific overview of adopting the standard reform model. Additionally, Foster and Rana (2020) synthesised findings from 27 papers in the World Bank's Policy Research Working Paper series to offer comprehensive insights on power reforms in developing countries. De Halleux et al. (2020) provide country-specific measures of the degree of reform adoption in the power sector in Latin America and the Caribbean based on factors such as market structure, private sector participation, regulatory autonomy and operational organisation. Collectively, these studies furnish essential data and insights that inform our classification of developing countries and our case selection process.

We hypothesise that developing countries in our Model 3+ and Model 2+ could be potential destinations for investment. These countries have wholesale markets and wholesale and retail markets. It is worth noting that many developing countries where investment in electric mobility and integration with electric utilities are increasing are in the Model 3+ and Model 2+ classifications. Table 2 shows the developing countries in the Model 3+ and Model 2+ classifications in our framework.

Table 2: Developing countries in Model 2+ and 3+ (the countries in bold font are analysed in this paper)

List of developing countries in Model 2+ and 3+	
Latin America	**Brazil, Chile, Colombia,** Guatemala, Argentina, Ecuador, El Salvador, Nicaragua, Peru.
Eastern Europe	**Türkiye**, Poland, Romania.
Asia	**India, China,** The Philippines.

Source: Authors' elaboration, de Halleux et al., (2020), Foster et al. (2020), Foster et al. (2017)

3. Country case studies on electric utilities and electric mobility interactions

We apply our framework to country case studies. Case studies are able to capture relevant information regarding qualitative details, identify their main aspects and dimensions and build theories on context-specific issues (Eisenhardt, 1989). The case studies aim to provide insight into whether our framework could apply to the electric mobility and electric power contexts in the developing countries we identified. We analyse six countries in the Model 2+ and Model 3+ classifications. In this paper, we focus on China and India (Asia), Brazil, Chile and Colombia (Latin America), and Türkiye (Eastern Europe). We selected these countries to comprehensively cover regional or continental differences while addressing country-specific local cases.

China

China’s power sector has the potential for emission reduction through reforms in the power sector (Xiang et al., 2023). China was responsible for 33% of the world's carbon emissions in 2020, and its power sector accounted for 43% of the country's total emissions. Thus, there is an ongoing policy focus on the deep decarbonisation of China's electric power sector through reforms based on ‘No. 9 Document of 2015’ to promote competition and enhance the operating efficiency of the power system with wholesale and retail power markets (Li et al., 2022; Xiang et al., 2023; Xie et al., 2022). Trading in China’s power market is mainly conducted through the power exchange centre, and the power dispatch, transmission, and distribution remain the responsibility of the grid company. On the supply side, generation companies compete to sell electricity directly to large consumers (Guo et al., 2020; Xie et al., 2022). Thus, we classify China as a Model 2+ country with wholesale power market plus peer-to-peer innovation with electric mobility in our framework.

Regarding decarbonisation, China’s plan to reach carbon neutrality in the coming decades will support its power and transport sector decarbonisation. Because the transport sector represents a significant source of China’s GHG emissions, developing strategies to work toward the deep decarbonisation of the transport sector are critical to meet the goal of carbon neutrality (Zhang and Hanaoka, 2021). China’s development of electric mobility can result in a significant reduction in emissions. If renewable energy sources energise electric mobility, transport-related emissions can be reduced with less use of fossil fuels and contribute to transport decarbonisation.

Moreover, the government’s ongoing policy support through the New Energy Vehicle (NEVs) Industry Plan (2021-2035) aims to promote transport electrification to reduce carbon emissions. NEVs include plug-in hybrid electric vehicles and battery and fuel-cell electric vehicles. The development of NEVs could improve China's energy security and environment by reducing its carbon emissions and dependence on oil imports (Yeung and Liu, 2023). This is in addition to other state, provincial and local policy supports. Notably, the national EV ownership reached 10.5 million in China by the end of 2022 (Yeung and Liu, 2023; Huang et al., 2021). Over 3.2 million EVs were sold in China in 2021, accounting for half of all electric vehicles sold worldwide and the highest percentage of the global electric bus fleet.

Regarding digitalisation, the demand for digitalisation of electric mobility is increasing; there are initiatives for a new networked, integrated control system solution for electric buses based on multi-protocol heterogeneous interconnection and a networked, integrated management system for electric buses (He et al., 2022). Moreover, the Chinese government supports the

development of new energy storage technologies (including smart charging[3]) and digital technologies development, such as smart collaborative control for energy storage (Zhang et al., 2023).

India

India's power sector is undergoing a transition that will have immense consequences for global decarbonisation efforts (Bhatia, 2023). Following years of efforts on power market reforms in India, the ''Electricity (Amendment) Bill 2020'' proposes competition in the supply business by introducing retail competition. Multiple retail suppliers are expected to increase the competition level since the customers may switch suppliers if they are not satisfied with the service quality of the present supplier (Agrawal, 2017; Jamasb et al., 2021). Thus, we classify India as a Model 3+ country with wholesale and retail electricity market plus peer-to-peer innovation with electric mobility in our framework.

Regarding decarbonisation with electric mobility, India may become one of the world's largest electric mobility markets. India appears to present many characteristics favourable to adopting electric mobility, including relatively low vehicle costs, a diversified fleet of two-wheelers, which offers a lifecycle cost advantage and electrification of buses (Briceno-Garmendia, 2022). India's 2070 carbon neutrality target requires deep decarbonisation in all sectors. Introducing electric mobility in the road passenger sector could offer a promising solution for meeting this target. Most state-level electric mobility policies support two and three-wheelers, EVs, and electric buses (Hossain et al., 2023). The FAME[4] programme provides incentives such as upfront subsidies for two- and three-wheelers, electric cars, buses, and charging infrastructure (Shrimali, 2021). Due to strong policy support, India has one of the most significant electric two- and three-wheeler (2/3W) markets worldwide. The Electric Mobility Promotion Scheme (EMPS) was introduced after FAME II to subsidise electric two- and three-wheeler purchases (Hossain et al., 2023; Arora and Gargava, 2023). Other support schemes are the GO Electric, National Electric Mobility Mission Plan (NEMMP) and state-level schemes that promote electric mobility in India (Digalwar et al., 2022).

To support India's aspiration to become self-sufficient in green energy technologies (Shrimali and Jindal, 2023), India has implemented an incentive program to support EV and component manufacturing, attracting billions of dollars in investment (Mittal et al., 2023). The production-linked incentive scheme incentivises companies to invest in establishing manufacturing units

[3] Smart charging in this sentence refers to smart charging management, power banks, and charging piles for electric vehicles (Zhang et al. 2023).
[4] Faster Adoption and Manufacturing of Hybrid and EV (FAME) Programme

for EVs and components like batteries to foster the growth of a robust domestic EV industry. Also, the phased manufacturing programme aims to increase the local sourcing of EV parts to achieve self-sufficiency in EV production by 2030 (Vengatesan et al., 2023). Moreover, the government has commenced a 10-year scheme to incentivise domestic battery manufacturing. The scheme is anticipated to attract about US$ 5 billion in investments from global battery manufacturers. India's e-mobility adoption is led by two and three-wheelers emerging as the first growth segments in India's e-mobility transformation because of their low costs. Electric vehicles are more expensive than ICEVs, offering a lower potential to increase adoption (World Bank, 2022). The EV Policy announced in March 2023 specifically targets attracting large investments from global EV manufacturers to set up production facilities in India (Vengatesan et al., 2023).

Regarding digitalisation, as the number of electric vehicles increases, it will have a notable impact on the power grid, and the need for digital technologies will become increasingly notable. EV charging could also offer demand response opportunities and reduce grid balancing costs when scheduled during high renewable energy generation periods (Abhyankar et al., 2023b). In this context, the charging infrastructure and power requirement of integrating electric vehicles into the grid can be supported by smart charging.

Brazil

Brazil initiated its first electricity reform in 1996 to incentivise private investment in electricity supply, foster competition within the generation and trading sectors, and mitigate investment risks. However, there was a power supply crisis in 2001 and 2002. In response to this crisis, a second reform was implemented in 2004 (Ribeiro et al, 2023). As a result of these reforms, the Brazilian power sector has become fully vertically unbundled with a functional wholesale market. In September 2022, Ordinance No. 50/2022 was approved, allowing high-voltage consumers to participate in the retail market from January 1, 2024 (Burin et al., 2023). Therefore, Brazil's retail power market commenced in 2024. Thus, we classify Brazil as a Model 3+ country with a wholesale and retail market plus peer-to-peer innovation with electric mobility in our framework.

With respect to decarbonisation with electric mobility, Brazil presents a specific context of electromobility investment that requires critical analysis because of the perceived competition of electromobility with the biofuel industry. Brazil is a large producer of sugarcane bioethanol. The Brazilian automotive fleet has a large share of flex-fuel vehicles. Therefore, investment in electric mobility does not appear to have the same momentum in Brazil as in India or China. Also, Brazil does not seem to be confronted with a rapid need for decarbonisation with electric

mobility, which biofuel may not offer. For example, battery electric vehicles in Brazil could provide significant emissions reduction potentials compared to gasoline-driven vehicles due to Brazil's predominantly renewable generation mix, making Brazil an attractive destination for large-scale electric mobility investment (Glyniadakis and Balestieri, 2023). However, sugarcane ethanol is also competitive in this regard. The energy mix of the Brazilian transport sector is composed of about 25% of renewable sources from biofuels, especially sugarcane ethanol, which represents about 43% of light vehicle consumption (de Halleux, 2020). Therefore, the biofuel industry stakeholders consider electric mobility a potential competitor. Stakeholders in the sugarcane sector oppose tax reductions for BEVs, arguing that it contradicts the objectives of promoting biofuel. Therefore, electric mobility investment initiatives should adapt to the specific context of Brazil and its evolving regulatory landscape.

Nonetheless, electric mobility investment has been growing in recent years, considering the need to reduce emissions. Significant investment in electric mobility is bringing a range of prototype electric mobility models into commercial production (Grangeia et al., 2023). However, the electric mobility market is still in the early stages of development (Kraemer et al., 2023). The National Agency of Electric Energy (ANEEL) has issued 'resolution No. 819', which provides a legal framework for battery electric vehicles, marking a milestone for the electric mobility market (Vargas et al. 2020). ANEEL also launched Strategic Call No. 22 (2020 - 2024) on electric mobility to demonstrate the techno-economic feasibility, generate business models, and propose policies and regulatory interventions to decarbonise public vehicle fleets, create zero-emission zones and other policy support schemes (Rosa, 2023).

Although electric vehicles (battery electric and plug-in hybrid electric vehicles) represented only approximately 1% of the total number of cars licensed in the country in 2020 (Ruoso and Ribeiro, 2023), the market is picking up and attracting investments. The entry of Chinese OEMs reflects the growth of the Brazilian electric mobility market. For example, BYD has opened a Li-ion battery manufacturing company and plans to expand its operations to manufacture batteries for electric buses. Moreover, electric mobility is anticipated to experience the highest growth rate with battery electric buses compared to other fuelling options. Electric buses are tax-exempt or with reduced tax rates in several Brazilian states (Briceno-Garmendia, 2022). It is also worth noting that two-wheelers account for (14.5 per cent), buses (1.0 per cent) and three-wheelers (0.2 per cent) of mobility in Brazil. Moreover, in 2023, Brazil launched the Green Mobility and Innovation Programme (2024-2028), which offers tax incentives to manufacture low-emissions technology（IEA, 2024b). Regulations and incentives related to electric mobility and utilities are evolving (Rai, 2023), and electric mobility implementation is snowballing on the policy front and infrastructure supply (Rosa et al., 2023).

In the context of the energy transition in the transportation sector, electric mobility seems to have become one of the promising focus areas for decarbonisation and a critical contributor to global GHG emissions reduction. Nonetheless, Brazil still requires effective actions to attract private investments for electric mobility (Grangeia et al., 2023; Vargas et al., 2020).

Regarding digitalisation and the integration of electric mobility, prosumers will likely be created, and peer-to-peer markets could be diffused using blockchain technology. Furthermore, some Brazilian electric utilities are exploring new digital platforms to help consumers better understand the free market. Some of these new platforms use blockchain technology and offer novel financial risk-sharing methods based on the customer's profile (Santos et al., 2021). Moreover, Brazil has pilot projects for smart grids, and several states are seeking to promote the adoption of smart meters.

Chile

Chile was the first country to perform power sector reforms in 1982 (Foster and Rana, 2020; Serra, 2022). Chile has a market-based mechanism to procure electricity for retail customers (Munoz et al., 2021). Thus, we classify Chile as a Model 3+ country with wholesale and retail electricity market plus peer-to-peer innovation with electric mobility in our framework.

With respect to decarbonisation with electric mobility, in 2019, Chile announced its plan to become carbon neutral by 2050. Among others, achieving this goal will involve significant transformations of the transportation and power sectors. For example, Chile has ambitious targets for electrifying its bus fleets for public transport. Chile has the second-biggest electric bus fleet in the world after China. Moreover, the government aims to ensure that all public transport vehicles are electric by 2040 and that sixty per cent of private vehicles are electric by 2050（IEA, 2024b). Some business models are also developing in Santiago, Chile. For instance, electric utilities purchased electric buses and leased them to operators to separate capital and operational costs (IEA, 2021). This is a public-private partnership or concession model between the state and electric utilities, which are the investors engaged under stable long-term contracts. Financing from traditional sources and bringing in incentives for electric utilities to invest and bear the technology risk could minimise the fiscal burden for the government. For Santiago's electric buses, fleet provision and depot ownership are separated from the operation of buses. There are two types of contracts: operations and infrastructure and assets contracts. Financing of charging infrastructure and electric buses was developed as part of a scheme in the electric utilities' core business, which developed leasing contracts with private bus operators to include monthly payments covering charging infrastructure, fleet provision, and energy supply (World Bank, 2020). The government guaranteed these

transactions for possible investment risks. This business model could also support the energy business for electric buses by providing flexible services for the power grid.

Regarding digitalisation, digital technologies are being deployed to facilitate electric mobility transactions in Chile. For example, the public transport system in Santiago operates bus companies integrated with a seamless electronic payment system that uses smart cards for revenue collection. Also, if there is insufficient local grid capacity to charge all electric buses simultaneously, smart charging could help to manage the charging of all the electric buses with the power available from the grid and ensure that electric buses are available for operation when needed (World Bank, 2020).

Colombia

Colombia has performed power sector reform, introducing private sector participation, independent regulation of distribution and transmission, and competition in power generation (World Bank, 2021). Colombia has an advanced power market with fully functioning wholesale and retail power markets. Thus, we classify Colombia as a Model 3+ country with a wholesale and retail power market plus peer-to-peer innovation with electric mobility in our framework.

With respect to decarbonisation with electric mobility, electric mobility procurement is increasing in Colombia, with notable growth in low-cost options, like Zhidou 2DS, which could be procured at a competitive price close to cost parity with the cheapest ICEV. Moreover, Colombia is focusing on electrifying mass transportation systems. There are ambitious targets for electrifying bus fleets; the government aims to fully electrify the public bus system fleet by 2035 (IEA, 2024b). There are also monetary and non-monetary policy incentives for electric mobility until 2027 through Decree 1116 of June 2017, and the law on the promotion of electric vehicles (Law 1964 of July 2019) promotes electric mobility for road transport. The National Strategy for Electric Mobility also aims to improve air quality and promote efficient transportation. The goal is to deploy 600,000 electric vehicles by 2030 and five fast charging stations in main urban areas by 2022 (Blanco et al., 2022). There is also a notable growth in the use of electric buses in Bogota, Cali, and Medellín in Colombia. Adopting electric buses can help achieve environmental protection goals and reduce non-renewable resource depletion (Zhou et al., 2024). Innovative financing models for derisking and separating capital from operational expenditure have supported electric bus deployment projects in Colombia. Regarding digitalisation, smart charging initiatives could be a key area that would be supported by digitalisation as the electric mobility market develops in Colombia.

Türkiye

Türkiye conduct electricity market reform (Erdogan et al., 2022). In 2008, the privatisation of Turkish distribution system operators (DSOs) started. The Turkish transmission system operator (TSO) is publicly owned, and all DSOs are privately owned. The power market is liberalised and regulated by the energy market authority, and the retail market was formally unbundled from distribution in 2013 (Kufeoğlu et al., 2019; Ahmed and Bhatti, 2019). Therefore, we classify Türkiye as a Model 3+ country with wholesale and retail electricity market plus peer-to-peer innovation with electric mobility in our framework.

Regarding decarbonisation with electric mobility, electric mobility investment appears to be slowly growing in Türkiye with policy support such as lower taxes. Nonetheless, the high upfront cost of BEVs relative to ICEVs and insufficient charging infrastructure seem to impact the adoption rate. One of the reasons why EVs have not become widespread in Turkey is the non-homogeneous spread of EV charging infrastructure in the country and the lack of regulatory oversight since the availability of charging infrastructure remains a crucial backbone for electric mobility deployment (World Bank, 2022). Thus, electric mobility requires more policy support in Türkiye (Gönül et al., 2021). Nonetheless, there are noteworthy cases illustrating electric mobility investment and deployment. For example, in Izmir, 835kW solar PV was installed on the depot roof to supply the daily energy need for 20 electric buses, with a plan to scale up to 400 buses by 2024 (IEA, 2021). Türkiye is also the first market outside Asia with the highest share of two and three-electric wheeler sales (IEA, 2024).

Regarding digitalisation, EV charging station companies in Türkiye are offering services, such as maps, through mobile applications and establishing common mobile platforms for EV charging that all EV users can access, see the station occupancy levels, get directions to alternative stations, and make online payments (IEA, 2024). It is anticipated that the growing electric mobility market could lead to increased implementation of digital technologies in Turkiye.

4. Discussions

The analyses of the developing countries' case studies in Model 3+ and Model 2+ in this paper describe ongoing electric mobility investment in the countries. With government policy support, proactive policies, and charging infrastructure development strategies, China offers a welcoming environment for adopting electric mobility, with notable progress in electric mobility investment. The growing proportion of electric buses, two- and three-wheelers, and electric vehicles in the overall market, as well as the advanced digital technological initiatives, demonstrate a high level of maturity in welcoming and supporting electric mobility private

sector investments. The private sector investments would also contribute to the joint decarbonisation of China's power and transport sectors. Policymakers could also embrace an approach that optimises investment in electric mobility charging infrastructure (Zeng and Qu, 2023).

In India, governmental efforts to promote electric mobility, install charging infrastructure important for adopting electric mobility, provide an enabling environment, encourage investments through financial incentives, and expand recharging infrastructure are noteworthy. The installation of charging network infrastructure is necessary (Lieven, 2015). The strategy seems that the different governmental subsidy schemes are anticipated to send the right signals to attract private-sector investments in a supportive regulatory environment (Shrimali and Jindal, 2023).

Brazil shows signs of development with tax incentives and an expanding charging infrastructure network. However, the share of electric mobility in the vehicle fleet is still low, and the country needs to overcome several obstacles to reach some level of maturity compared to China or India. Among others, the perceived competition with the competitive cost of biofuels is worth noting, while biofuels in ICEVs can also offer immense contributions to achieving decarbonisation goals. Therefore, electric mobility and biofuels can complement each other in Brazil. Nevertheless, it is noteworthy that the electric mobility market is growing in Brazil, with hundreds of electric buses deployed (notably in São Paulo) and over 130,000 electric vehicles in 2022 and charging infrastructure deployment (Kraemer et al., 2023).

Chile is also experiencing market growth in electric mobility, which is led by a preference for electric buses in the public transport system. Over a thousand electric buses are in operation in Chile. Electric bus charging infrastructure could also be integrated with smart grid technologies to enable demand response capabilities and support load-balancing activities of the electric utilities. The burgeoning business models and public and private partnership initiatives with electric utilities to attract investment and deploy digital tools to facilitate transactions are also worth noting.

In Colombia, the electric mobility investment landscape is similar to Chile, with notable growth in electric buses for public transportation and low-cost and competitive electric vehicle options. The growth is also supported primarily by government policies that provide support schemes and investment guarantees in addition to regulatory support and innovative financing models with the expectation that electric mobility will contribute to the country's decarbonisation objectives.

In Turkey, policy support to create an enabling environment for investment in transport electrification with electric mobility is also notable, albeit significantly hampered by the chicken-and-egg problem of the lack of investment in charging infrastructure leading to low procurements of electric mobility and vice versa. It also appears that the government policy support in Türkiye is currently not at the level observed in India, China or Chile.

Concurrently, it is important to discuss the impact of load increase on the power grid and the possible need for additional investments in reinforcing the grid infrastructure. Charging two- and three-wheelers may not lead to significant increases in peak load because of their low charging power until a high level of penetration, but charging of buses could increase peak load (IEA, 2023). Therefore, there is a need for careful charging infrastructure planning, for example, at the electric bus depots.

In sum, the government's policy support appears the sine qua non spurring private sector investments in the six developing countries analysed in this paper. The key elements for progress include providing incentives, charging infrastructure investments, and developing robust policies for digitalising and decarbonising transport and energy services. Focusing on these areas can create a favourable environment for investment in electric mobility. Besides, designing workable and sustainable business models through public-private partnerships (PPP hereafter) can also attract investments. China, India, Chile, and Colombia seem to offer examples of the efficacy of the PPP model in attracting electric mobility investment. Brazil and Türkiye can learn from these models and adapt them to their local contexts. It is worth noting that the six countries analysed focus on the low total cost of ownership solutions. There is a high preference for and proliferation of low total cost of ownership two and three-electric wheelers in India and China (Asia) and electric buses in Chile and Colombia (Latin America). China, India, Chile, Colombia and Brazil are electrifying their bus fleets in their largest cities through innovative financing and improved procurement practices. The evolving success stories in China, India, and Chile can be adapted to Turkey, which seems to be the lowest among the six countries in attracting electric mobility investment. However, there is a need for caution because of the specific local context of Turkey. Although some initiatives and tax incentives have been implemented in Turkey, the relatively low level of legislative and political support needs to be increased to promote an enabling investment environment.

Regarding investment innovation, carefully designed public-private partnerships that provide access to investment and risk sharing tailored to the specific local contexts are needed. Also, digital technologies could support emerging business models and facilitate transactions in the interaction of electric mobility and electric utilities. Digital technologies could also support payment systems to offer consumers different payment options with smart charging initiatives.

Finally, because the advantage of electric mobility could stem from operating cost savings, the most intensively used electric mobility are those likely to present the most favourable cost-benefit analysis, which are two and three-electric wheelers and electric buses.

Limitations of our framework and future research

We add a caveat that while our framework and analyses could help identify developing countries for electric mobility investment, it should be considered complementary and not a replacement for other electric mobility investment due diligence processes. Furthermore, case studies as a research method, while useful for capturing in-depth qualitative details, have generalisability limitations beyond specific contexts, and there could also be potential for researcher bias from subjective analyses. In future works, based on data availability, we would like to test our hypotheses with quantitative data and statistical methods to offer quantitative empirical evidence. These limitations should be considered when using our findings for decision-making. Furthermore, we would attempt to study in future research whether the anticipated better performance of Models 2+ and 3+ compared to Models 1+ and 4+ could be due to poor coordination with complementary public measures.

5. Conclusion and policy implications

Electric mobility seems promising for the decarbonisation of the transport and power sectors. Nonetheless, many developing countries are financially constrained to make substantial electric mobility investments. Moreover, investors need insights on which developing countries to invest in and what electric mobility solutions. Therefore, securing investments for electric mobility remains challenging in many developing countries. Prior research generally identified lack of grid power access, small grid size, charging infrastructure and investment costs as challenges to electric mobility deployment in many developing countries. We build upon existing literature and answer the research question on how electric mobility private sector investment can be harnessed in the power and transport sector interaction context in developing countries.

We contribute to the literature with case studies to validate China, India, Brazil, Chile, Colombia and Türkiye as developing countries investors could consider for electric mobility investment. We argue that developing countries with wholesale power markets, and wholesale and retail power markets could attract electric mobility investment, albeit with a proliferation of low total cost of ownership electric mobility investment options such as two and three-electric wheelers and the proliferation of investment in electric buses for public transport that is perceived to have notable environmental benefits.

Thus, we argue that our framework and analyses could be helpful for policymakers and stakeholders in the power and transport sectors to identify developing countries for electric mobility investment. Furthermore, our analyses suggest the critical role of governmental support and the need to focus on low total cost of ownership investment options in developing countries. Based on our analyses, we provide the following policy recommendations:

- *Developing countries with wholesale and wholesale and retail power markets could be viable electric mobility investment destinations.* These countries have more advanced power systems and electric utilities that could make them worthwhile destinations for investment compared to developing countries with vertically integrated utilities or single-buyer models.

- *Adaptable regulatory frameworks are needed to support the growing electric mobility market in developing countries with wholesale and wholesale and retail power markets.* Our analyses of the six countries show that the countries with more robust regulatory frameworks, such as China, have made more significant progress than the others in attracting private-sector electric mobility investment. Therefore, policymakers need to develop robust policy frameworks to support electric mobility investments in the countries.

- *Sustainable business models are required for electric mobility private sector investment in developing countries based on specific local contexts*. A one-size-fits-all solution is unlikely to attract the much-needed private sector investment. Therefore, policy support in developing countries with wholesale and wholesale and retail power markets could focus on supporting the burgeoning, market-driven business models for their specific local context.

A future research direction is to conduct case studies of the other countries identified in our framework and cross-country comparisons and analyses.

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