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How to align investments for electric mobility in developing countries? Insights from case studies

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Abstract

Electric mobility seems promising for the decarbonisation of the transport and power sectors. Nonetheless, making investment decisions on electric mobility in developing countries remains topical in policy and academic debate. This paper contributes to the debate in the context of decarbonisation and digitalisation to understand investment decision-making on electric mobility. We propose and validate a framework with case studies on electric mobility investments in China, India, Brazil, Chile, Colombia and Türkiye. We argue that the status quo of power sector reforms in developing countries and the interaction of electric utilities and electric mobility could provide insights into the developing countries to invest in electric mobility. We also 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 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 as an investment decision-support tool for private sector-led electric mobility investment in developing countries.

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

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). It is anticipated that the transformation of energy systems towards a net-zero future could accelerate the development of innovative and efficient technologies to provide clean, sustainable and affordable energy solutions (Yiji et al., 2021). 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. Approximately 20% of the total global CO₂ emissions come from the transport sector, and 71% of these CO₂ 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 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 CO₂ emissions (Yuan et al., 2024); and increased prospects of contributing to reducing CO₂ 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 sales (for example, EVs and two and three-wheelers) are rising with increasing policy support (IEA, 2024a). Moreover, electric mobility can play a role in energy communities by reducing carbon emissions, strengthening grid resilience and contributing to a sustainable energy transition (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). As developing countries aim to achieve net zero emissions, integrating electric mobility into the power and transport sectors could help to jointly decarbonise both sectors. Therefore, there is interaction between electric mobility and utilities as electric mobility operates in an ecosystem with actors from the power and transport sectors.

When electric mobility is integrated into the power grid, the grid should be capable of handling intermittent energy supply sources, two-way electricity transactions, and data flow. 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, 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 balance intermittent renewable power generation. 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.

In this paper, we contribute to the extant literature on electric mobility investment in developing countries from the viewpoint of the interaction between the power and transport sectors. We focus on decarbonisation and digitalisation. Building upon insight from the framework developed in Arowolo and Perez (2023), we conduct case study analyses of the interaction of electric utilities and electric mobility in six developing countries (China, India, Chile, Brazil, Colombia and Türkiye) that position them as potential electric mobility investment destinations. First, we analyse electric mobility investment in six developing countries (Asia, Latin America and Eastern Europe) in the context of the interaction of electric utilities and electric mobility. Second, we offer broad insights into electric mobility investment in the contemporary complexities of decarbonisation and digitalisation in developing countries. Third, we provide in-depth knowledge for investors, academics, policymakers, and other stakeholders to understand electric mobility investment in developing countries.

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

2. Materials and methods

This section offers two main insights. First, we explain decarbonisation and digitalisation in the context of the interaction of electric utilities and electric mobility. Second, we provide a background understanding of the framework we build upon in this paper. Arowolo and Perez (2023) conducted a comprehensive literature review of different strands of literature related to electric mobility investment in developing countries. Then, the authors proposed a framework as an investment decision-support tool to identify some developing countries that could be considered for electric mobility investments.

2.1 Decarbonisation and digitalisation in the context of the interaction of electric utilities and electric mobility.

For electric utilities, decarbonisation implies a shift in power generation sources. Decarbonisation strategies, pivotal in reducing emissions, encompass developing and implementing actions to reduce CO₂ emissions in the power and transport sectors. These may include renewable energy adoption, energy efficiency measures or switching to low-carbon fuels (Mosso et al., 2024). Digitalisation is the increasing use of communications and

information technologies in transport and energy systems (IEA, 2017). For example, for EVs to support larger power system objectives, they need to be able to adjust charging immediately the system sends a signal. The faster the EVs can react, the more services it can provide. Such high levels of coordination can happen through digital technologies. Also, with digital technologies, smart charging service providers can serve as intermediaries to balance the needs of EV users, charge point operators and power systems (IEA, 2023).

2.2 Framework on the interaction between electric utilities and electric mobility in the developing countries' context

2.2.1 Industrial organisation model of electric utilities

We describe the industrial organisation models of electric utilities and propose new ones to explain the contemporary state of electric utilities with the increasing impact of electric mobility in the context of decarbonisation and digitalisation.

2.2.1.1 Vertically integrated utility model

Prior to power market reform in many countries, electric utilities were vertically integrated monopolies under the government's control. The vertically integrated utilities were responsible for generating, transmitting, distributing and retailing electricity to consumers. However, the state-controlled vertically integrated utilities suffered from low efficiency, and taxpayers bore most of the investment risks. Moreover, in some developing countries, the government lack sufficient financial resources to invest in the highly capital-intensive power sector as the state budget competes with other priorities. This resulted in poor service quality and the clamour for market-oriented reforms to reduce the state's exclusive ownership and control of the power sector by implementing the standard electricity reform model proposed by some multilateral institution(s). 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).

2.2.1.2 Wholesale Electricity Market Model

Since the 1980s till date, 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 the wholesale market model, the electric utilities' generation, transmission and distribution functions are unbundled, and there is competition among power generators. At the same time, transmission and distribution remain services offered by monopolies that are often subject to regulatory supervision to ensure proper market conduct and performance. The anticipated benefit of unbundling and privatisation is that the electric utilities could earn the revenues they need with cost-reflective tariffs if properly regulated. Other benefits include access to private-sector investments and the optimal allocation of economic resources to maximise societal welfare. Moreover, market reforms may be worthwhile in developing countries where governments lack investment funds. Therefore, many developing countries attempted to establish wholesale power markets.

2.2.1.3 Wholesale and retail electricity market model

Some developing countries further established competition in the retail market. In the wholesale and retail market model, all the participants have full access to the market. Consumers can procure their energy from competing retail suppliers instead of the distribution utility. As new technologies are introduced on the supply (such as renewable energy and battery storage) and demand (such as electric vehicles) sides, more significant market design challenges are posed to many countries, whether they have a working market or are considering establishing one. Introducing wholesale and retail competition could provide more significant incentives to reveal information about the best operating and investment options and facilitate the entry of new, more efficient plants and market participants (ESMAP, 2022).

2.2.1.4 The Single-buyer Model

Many developing countries did not completely implement power market reforms because of the challenges of implementing all the standard electricity reform model processes. These processes, among others, require establishing competition in the wholesale and retail power markets, which was challenging for many developing countries. For example, the long-term contracts that induce independent power producers to invest in power generation may hamper competition (Foster and Rana, 2020). Therefore, the reform process was not completed in many developing countries. This resulted in a hybrid model in which state control coexists with private ownership in the power markets, resulting in the so-called 'single-buyer model'. In this model, the independent power producers compete with existing generation to supply electricity to a single buyer, which is usually the transmission or distribution utility or a publicly owned special-purpose vehicle.

2.2.1.5 Peer-to-Peer innovation with electric mobility model

A progressive peer-to-peer innovation with electric mobility is unfolding in developed and developing countries. This innovation is an unorganised market based on peer-to-peer energy and transport services (see Figure 1).

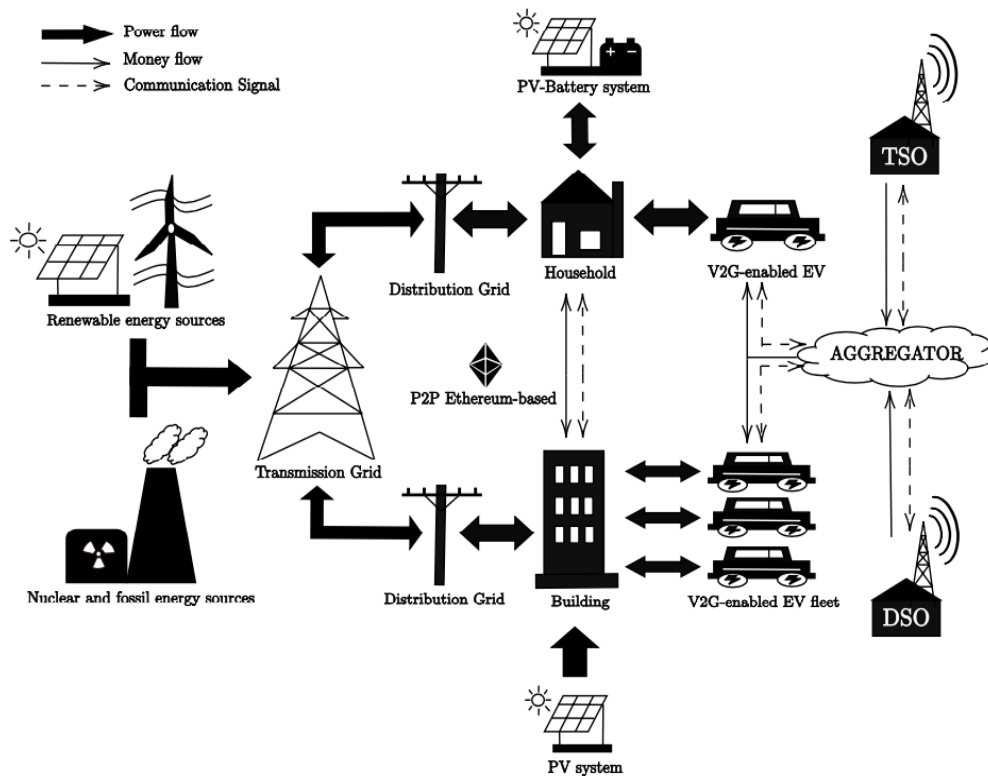


Figure 1: Peer-to-peer innovation with electric mobility. Source: (Gomes et al. 2020)

This innovation integrates new decentralised storage solutions (such as electric mobility and battery energy storage systems), renewable energy sources and digitally enabled information and communication technologies that enable signal processing. Furthermore, the peer-to-peer innovation model incorporates new market actors and stakeholders, such as aggregators and electric mobility original equipment manufacturers (OEMs). Other notable burgeoning developments in the peer-to-peer innovation with electric mobility model include bidirectional power flow and active management of increasingly digitalised power generation, transmission and distribution networks (Gomes et al. 2020).

In this model, digital technology can enable bi-directional power flow among residential and commercial buildings and the distribution grid. Moreover, peer-to-peer energy trading can occur between commercial or residential buildings. The aggregator can create value by coordinating transactions between electric mobility owners and electric utilities. For instance, the aggregator can coordinate EV fleet participation in the power markets. The aggregator can also facilitate distributed energy resources supply to the power market, for example, through renewable energy auctions or other transactions in the power (energy or reserve) market, based on the allowed network-safe limit. The burgeoning peer-to-peer innovation with electric mobility model has a higher level of digitalisation than the industrial organisation models. For example, advanced peer-to-peer trading technologies and communication signals (digitalisation) support power flow from EVs with a high level of decentralised power generation and renewable energy generation sources to facilitate decarbonisation.

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 (see Figure 2). We coin

the transformation of the electric utilities industrial organisation as Model 1+, Model 2+, Model 3+ and Model 4+.

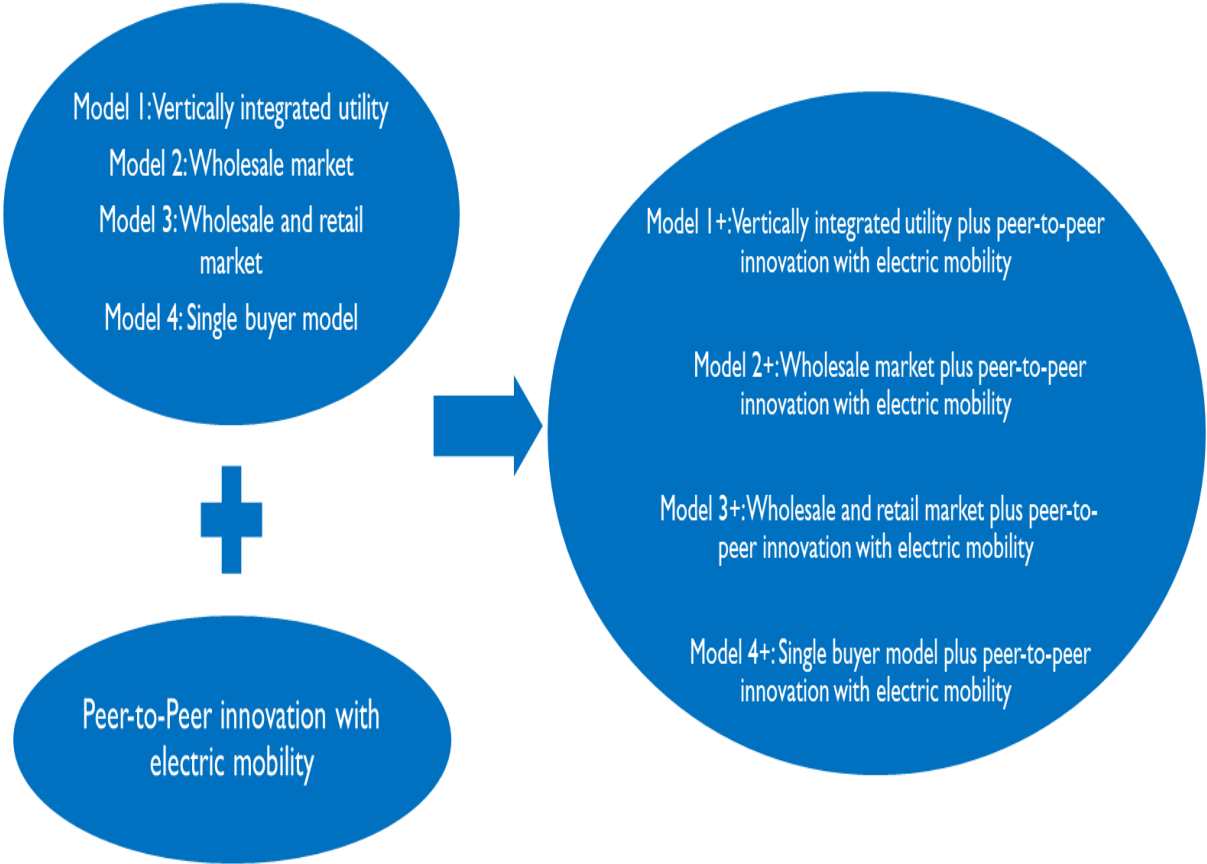


Figure 2: Utilities transformation by the peer-to-peer innovation with electric mobility

Building upon the preceding analysis, we present our new electric utilities' interaction with electric mobility industrial organisation framework to explain 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 Utilities and electric mobility framework for developing countries.

The plus sign represents the order of magnitude of the increasing impact of digitalisation and decarbonisation on electric utilities depending on their industrial organisation model. This means that the higher the level of power market reform plus peer-to-peer innovation with

electric mobility, the higher the expected impact of digitalisation and decarbonisation on the electric utilities' industrial organisation. The magnitude of the transformation of the utilities with electric mobility caused by the impact of decarbonisation and digitalisation is lowest in developing countries that are yet to perform power sector reforms, that is, Model 1+ (vertically integrated utility plus peer-to-peer innovation with electric mobility) classification. Then, it is followed by the countries with the single-buyer model (Model 4+), while developing countries with wholesale power markets (Model 2+) and functional wholesale and retail power markets (Model 3+) have the highest levels of digitalisation and decarbonisation impacts.

Many countries in Sub-Sahara Africa appear to fall in this Model 1+ classification. For example, vehicle-to-grid, peer-to-peer trading, and burgeoning aggregator business models are not topical issues of electric utilities in Sub-Sahara Africa (SSA). EV ownership rate and charging infrastructure access are low in SSA, and peer-to-peer energy trading and aggregator business models are not topical. The topical issues include investment in electricity access, curtailing transmission and distribution (technical) losses, curtailing non-technical losses or theft, the financial viability of electric utilities, system interruption or blackouts, and addressing institutional design issues. Therefore, the developing countries in Model 1+ have the lowest impact of decarbonisation and digitalisation (Table 1). When a developing country either performs a power sector reform or progresses in the reform process and moves to the next model, for example, from the vertically integrated utility (Model 1+) to the single buyer with electric mobility (Model 4+), we expect the impact of decarbonisation and digitalisation to increase.

Applying the insight from the framework in Table 1, we study the literature (Foster et al., 2017; Foster and Rana, 2020; de Halleux et al., 2020) on the current industrial organisation of electric utilities in most developing countries. We list (see Table 2) the developing countries in the Model 2+ and Model 3+ classifications in our framework. These countries have functional wholesale power markets and wholesale and retail power markets. Notably, most developing countries where electric mobility investment and integration with electric utilities are gaining traction are in the Model 2+ and Model 3+ classifications.

Table 2: List of developing countries in Model 2+ and 3+.

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

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

3. Country case studies

We apply our framework for in-depth country case studies. We select six countries with available data representing forty percent of the identified Model 2+ and Model 3+ countries for further analysis. The countries are China and India (Asia), Brazil, Chile and Colombia (Latin America), and Türkiye (Eastern Europe).

China

China's power sector has the potential for emission reduction, and the country is approaching its goal of carbon neutrality 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 retail companies and large consumers (Guo et al., 2020; Xie et al., 2022). In 2019, power retailers, through the market mechanism, accounted for nearly 40% of the electricity consumption of China (Wang and Wang, 2023). Thus, we classify China as a Model 3+ country with wholesale and retail power market plus peer-to-peer innovation with electric mobility in our framework.

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. Furthermore, as the demand for digitalisation and intelligence of electric mobility increases, 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; Kraemer 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, 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.

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 FAME¹ programme provides incentives to support investment in charging infrastructure for electric buses. 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).

India has implemented an incentive program to support EV and component manufacturing, attracting billions of dollars in investment (Mittal 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).

Brazil

Following the reform of the Brazilian power sector, it is fully vertically unbundled with a functional wholesale market. Implementing its retail market that will enable small consumers, including residential ones, to participate in the free market is pending and scheduled for 2024 (Santos et al., 2021). Thus, we classify Brazil as a Model 2+ country with a wholesale market plus peer-to-peer innovation with electric mobility in our framework.

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 offer 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 et al., 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

¹ Faster Adoption and Manufacturing of Hybrid and EV (FAME) Programme

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 investments in electric mobility are 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 are evolving, 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, Brazil has some pilot projects for smart grids, and several states are seeking to promote the adoption of smart meters. With 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).

Chile

Chile was the first country to perform power sector reforms four decades ago (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.

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. 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 power markets. Thus, we classify Colombia as a Model 2+ country with a wholesale power market plus peer-to-peer innovation with electric mobility in our framework.

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.

Türkiye

Türkiye is one of the countries that adopted power 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.

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 supply that all EV users can access, see the station occupancy levels, get directions to alternative stations, and make online payments.

4. Discussions

The case studies of developing countries in Model 2+ and Model 3+ analysed in this paper reflect ongoing electric mobility investment in these countries. With government policy support, proactive policies and charging infrastructure, China offers a welcoming environment for adopting electric mobility with remarkable 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.

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 strategy seems to be that the different governmental support schemes are anticipated to send the right signals to attract private-sector investments.

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 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 like 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. We summarise the insights from our analyses in Table 3.

	Electric Utilities Industrial Organisation model	Decarbonisation	Digitalisation
China	Wholesale and retail power market plus peer-to-peer innovation with electric mobility Model 3+	High decarbonisation potential with policy support	High digitalisation potential
India	Wholesale and retail power market plus peer-to-peer innovation with electric mobility Model 3+	High decarbonisation potential with policy support	High digitalisation potential
Chile	Wholesale and retail power market plus peer-to-peer innovation with electric mobility (Model 3+)	High decarbonisation potential with policy support	High digitalisation potential

Brazil	Wholesale market plus peer-to-peer innovation with electric mobility (Model 2+)	Decarbonisation potential with policy support but not as high as China or India	Digitalisation potential
Columbia	Wholesale and retail power market plus peer-to-peer innovation with electric mobility (Model 2+)	Decarbonisation potential with policy support	Digitalisation potential
Türkiye	Wholesale market plus peer-to-peer innovation with electric mobility (Model 3+)	Decarbonisation potential with policy support but not as high as China or India	Digitalisation potential

Table 3: Insights from case study analyses

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 investment in charging infrastructure, increasing financial incentives and subsidies, and developing robust policies for decarbonising and digitalising energy and transport services. Focusing on these areas can create a favourable environment for investment in electric mobility. Besides, designing sustainable business models through public-private partnerships (PPP hereafter) can also attract investment. 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 suitable for specific local contexts are needed. Also, digital technologies could play important roles in supporting emerging business models and facilitating transactions in the interaction of electric mobility and electric utilities. Digital technologies could also support payment systems and offer consumers different payment options, such as static or dynamic pricing or tariffs, payment per trip, or monthly subscriptions, which could also support digitally enabled electric mobility 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.

5. Conclusion and policy implications

This paper attempts to contribute to the literature on electric mobility investment in developing countries. First, we explain our framework for the contemporary interaction between electric utilities and electric mobility in developing countries. Then, we apply our framework for country case studies and analyses in the context of decarbonisation and digitalisation in six developing countries: China, India, Brazil, Chile, Colombia and Türkiye. We argue that the state of power market reforms in developing countries and the interaction of electric utilities and electric mobility in the context of decarbonisation and digitalisation could provide insights into the developing countries to consider for electric mobility investment. We also argue that developing countries with wholesale power markets, and wholesale and retail power markets seem to attract electric mobility investment, albeit with an initial 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 as an investment decision-support tool for electric mobility investment in developing countries. 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.

We contribute to the existing literature in three significant ways. (i.) Using a case study approach and building upon our developed framework, we analyse electric mobility investment in six developing countries in the context of the interaction of electric utilities and electric mobility. (ii.) We offer a broad insight into electric mobility investment in the contemporary complexities of decarbonisation and digitalisation in developing countries. (iii.) We provide in-depth knowledge for investors, academics, policymakers, and other stakeholders to understand electric mobility investment in developing countries. Based on our insights and analyses, we offer the following policy recommendations:

- **Developing countries with wholesale power markets and wholesale and retail power markets could be viable electric mobility private sector 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.
- **There is a need for robust regulatory frameworks to support the burgeoning electric mobility ecosystem in developing countries with wholesale power markets and wholesale and retail power markets.** Our analyses of the six countries show that the countries with more robust regulatory frameworks have made more significant progress than the others in attracting private-sector electric mobility investment.
- **Public policy support is crucial for enabling electric mobility private sector investment in developing countries.** Beyond the well-known incentive schemes, tax rebates, subsidies, regulatory support and nudging strategies, governmental guarantees and other derisking initiatives are necessary to reduce investment uncertainties and attract electric mobility investment in developing countries.

- **Sustainable business models are required for electric mobility private sector investment in developing countries.** The business models would have to be adapted to the specific local context of the countries. A one-size-fits-all solution is unlikely to attract the much-needed private sector investment.

A future research direction is to conduct in-depth case studies of the other countries identified in our framework and cross-country comparisons and analyses. Furthermore, we could also provide insights on whether countries in Model 3+ countries could be the most viable investment destinations or those in Model 2+ with cross-country analyses. Finally, we add a caveat that while our framework and analyses could be helpful as a decision-support tool for electric mobility investment in developing countries, it should be considered a complementary tool and not a replacement for other electric mobility investment due diligence processes.

Data Availability

Data will be made available upon request.

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