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Electric mobility investment in the power and transport sector coupling context: lessons from Argentina, the Philippines, Poland and Romania

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Abstract

Many developing countries are at a crucial juncture in road transport electrification with electric mobility because they have limited economic capacity to implement government policy support and financial mechanisms that have spurred the capital-intensive electric mobility growth in developed countries. Attracting private sector investments remains a viable option for developing countries. While investors have identified opportunities to invest in developing countries, it remains to be seen which countries to prioritise, considering the complexities involved in investment decision-making despite the availability of myriad investment appraisal tools. This paper contributes to this academic and policy debate. With a power and transport sector coupling viewpoint, we explain the interaction of the power and transport sectors in the context of decarbonisation and digitalisation to identify developing countries that could be considered for private sector investment in electric mobility. Then, we apply our framework to case studies of the Philippines, Argentina, Romania, and Poland. We argue that countries with wholesale power markets and wholesale and retail power markets could attract electric mobility investment. We offer policy recommendations for stakeholders interested in electric mobility investment issues in developing countries.

Keywords: investment, electric mobility, energy transition, developing countries, decarbonisation, digitalisation.

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1. Introduction

The energy transition aimed at curtailing emissions and combating climate change is transforming the power and transport sectors. These sectors are major consumers of energy and some of the most significant contributors to global greenhouse gas emissions. For instance, the transport and energy sectors were responsible for over 60% of global CO₂ emissions in 2022 (IEA, 2023). Net zero emissions involve decarbonising the economy, including energy demand and supply, transport and other emission sources (Logan et al., 2023). The transformation of energy systems towards net zero emissions could support the growth of innovative and efficient technologies for sustainable solutions. In the power sector, the transformations are notable with the introduction of renewable energy sources and energy storage systems. Likewise, the transport sector requires electrification with electric mobility to combat climate change (Logan et al., 2023). The global transport sector accounts for 25% of the world's energy consumption and is a major sector contributing to greenhouse gas emissions (Tzeiranaki et al., 2023). Road transport is responsible for over 70% of emissions in the transport sector (IEA, 2023). Electric mobility appears as a promising alternative to internal combustion engine vehicles (ICEV) to reduce transport emissions and support energy-efficient and sustainable mobility (Martins et al., 2023; Aznar et al., 2021; Ahmad et al., 2024). Electric mobility could also support the decarbonisation of the power sector with decentralised, flexible energy storage solutions. Electric mobility becomes more valuable for reducing emissions when powered by renewable energy sources and could help reduce road transport's primary energy consumption. Integrating electric mobility into the transport sector could support coupling the transport and power sectors with the potential to synergise clean transportation and use low-carbon power solutions (Ahmad et al., 2024; Guo et al., 2021). Therefore, there is interaction between electric mobility and electric utilities as electric mobility operates in an ecosystem with actors from the power and transport sectors (Arowolo and Perez, 2023a).

Nonetheless, the intermittency of renewable energy sources could pose new challenges for the power sector. 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, there are possible solutions through digital technologies with sensors, smart grids, and artificial intelligence. This could lead to a more digitalised power system, where consumers become active participants as prosumers (Fuchs et al., 2024). Through real-time monitoring and advanced data analytics to facilitate the transition to a more sustainable and resilient energy system, power system digitalisation could support decarbonisation and enhance grid management, reliability, and efficiency.

The transition to electric mobility could support decarbonising the transport sector in developing countries (Sunio and Mendejar, 2022; World Bank, 2023b). Moreover, developing countries need more sustainable, efficient, safe, and inclusive means of transportation to improve their citizens' quality of life (Bianca et al., 2023). Electric mobility and digital technologies could also offer promising solutions for mitigating climate change impacts in developing countries. It is worth noting that electric mobility is increasingly gaining the attention of policymakers as a possible solution to achieve clean and green transport and improve the energy security of supply in some developing countries (Yanfei et al., 2019).

Nonetheless, it is challenging to implement electric mobility and digital solutions in developing countries. Among other reasons, governments in developing countries often have limited budgetary allocations required for capital-intensive transport electrification and digitalisation investments. The economic problem of scarce resource allocation to alternative needs usually requires complex decision-making processes on what should be the priority or appropriate investment decision (Bhattacharyya, 2011). The de facto reliance on multilateral and bilateral institutions' conditional debt financing and international aid is unsustainable and insufficient to meet many developing countries' investment needs. The status quo mechanisms of foreign debt financing, public development assistance or aid often support market opportunities for foreign rather than domestic entities. Moreover, it brings an associated risk of increased aid dependency and the difficulty of tackling complex, country-specific issues, in addition to the conditionalities to which recipient developing countries are subjected (Trotter and Abdullah, 2018). Therefore, harnessing private sector investments remains a viable option for developing countries.

Thus, this paper attempts to answer the research question: How to harness electric mobility private sector investment in developing countries in the power and transport sector coupling context?

We contribute to the literature on electric mobility investment in developing countries from the viewpoint of the interaction between the power and transport sectors. Building upon insights from the framework developed by Arowolo and Perez (2023b), we conduct case studies of the interaction of electric utilities and electric mobility and draw relevant lessons on investment in electric mobility in four developing countries (Argentina, Poland, Romania, and the Philippines). Then, we offer lessons on electric mobility investment for investors, academics, policymakers, and other stakeholders interested in electric mobility investment issues in developing countries.

This paper proceeds as follows. Section 2 discusses the materials and methods. Section 3 presents the country case studies. Section 4 is the discussion and analysis. Section 5 is the conclusion and policy implications.

2. Materials and methods

This section describes the framework we apply in this paper based on our previous works. Arowolo and Perez (2023b) conduct a comprehensive literature review of different strands of literature related to electric mobility investment in developing countries in the context of the interaction of electric utilities and electric mobility. Then, we propose a framework to identify some developing countries that could be considered for electric mobility private sector investments. Arowolo et al. (2024) conduct context-specific case studies for six countries to validate the 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. In this paper, we extend these existing research works with the case studies of Argentina, the Philippines, Romania and Poland. We selected these four countries for analysis to explore regional differences while providing insights into country-specific challenges and possible solutions.

In this section, we provide a contextual background of our framework with a description of the industrial organisation models of electric utilities.

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

Arowolo and Perez (2023b) and Arowolo et al. (2024) propose new industrial organisation models to explain the contemporary state of electric utilities with the increasing impact of electric mobility in the context of decarbonisation and digitalisation.

Vertically integrated utility model (Model 1)

Before power market reform in many countries, electric utilities were vertically integrated monopolies under the government's control. The vertically integrated utilities generated, transmitted, distributed, and retailed electricity to consumers. However, the state-owned 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 outcry for market-oriented reforms to reduce the state's exclusive ownership and control of the power sector.

Electricity market reforms were embarked upon to improve power system operational and planning efficiencies. Market reforms could also transfer technology and cost risks from consumers to investors (Conejo and Sioshansi, 2018). It was anticipated that the transformation of state electric utilities into business entities, the establishment of independent regulatory authorities and the total or partial transfer of construction, operation and maintenance activities to the private sector would also reduce fiscal pressure on the State's budgets and enhance efficiency improvements (Cherni and Preston, 2007).

Wholesale Electricity Market Model (Model 2)

In the 1980s and 1990s, beginning with Chile, market reforms were embraced as part of a shift in economic reasoning and policy from state control to private ownership with the introduction of market competition and private investments with the expectation to improve efficiency (Lee and Usman, 2018). In the wholesale market model, the electric utilities' generation, transmission, and distribution functions were unbundled, and competition was introduced among power generators. Transmission and distribution remain services monopolies offer and were subject to regulatory supervision to ensure proper market conduct and performance. If properly regulated, the anticipated benefit of unbundling and privatisation is that the electric utilities could earn the revenues they need with cost-reflective tariffs. 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 tried to establish wholesale power markets.

Wholesale and Retail Electricity Market Model (Model 3)

Some developing countries further established competition in the retail market. In the wholesale and retail market model, all the participants have access to the market. Consumers can procure their energy from competing retail suppliers instead of the distribution utility. As innovative technologies are introduced on the supply and demand 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 market participants. The retail market structure could also enable competing firms to offer different terms of retail electricity services, which may include active demand-side management to consumers (Conejo and Sioshansi, 2018).

The Single-buyer Model (Model 4)

Many developing countries have not completely implemented 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 the State’s 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 firms to supply electricity to a single buyer, usually the transmission or distribution utility or a publicly owned entity established for this purpose.

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).

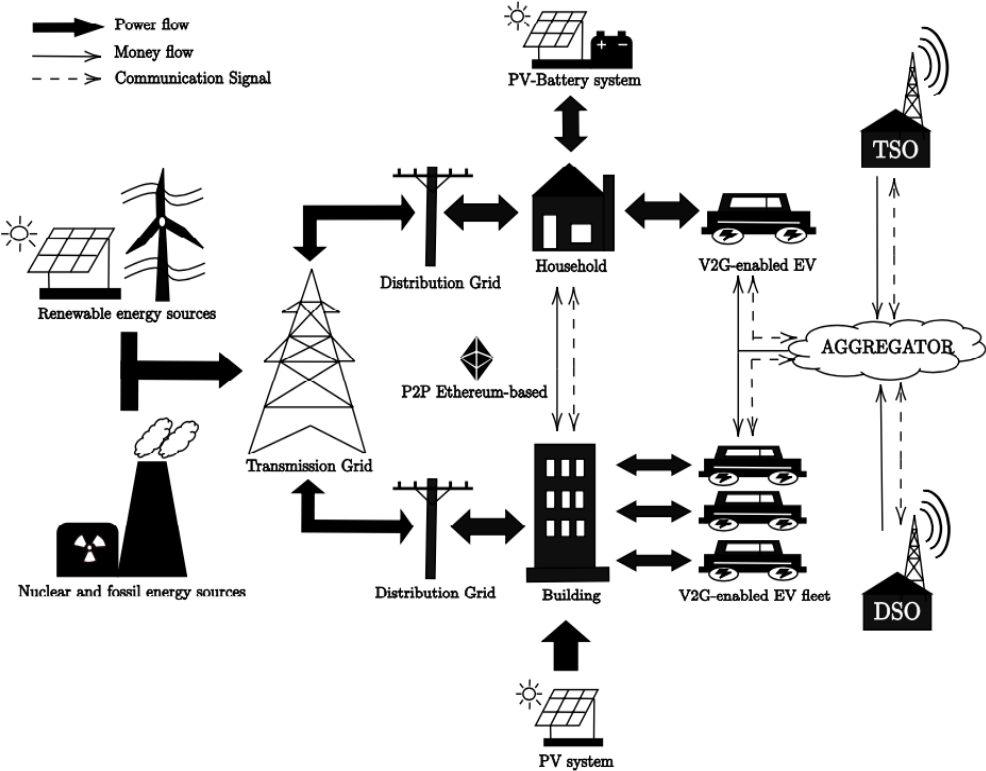


Figure 1: Peer-to-peer innovation with electric mobility. Source: Gomes et al. (2020)

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 to facilitate 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, smart metering and peer-to-peer energy trading can occur between commercial or residential buildings. Electric vehicles can supply power to the grid and residential and commercial buildings. In this context, 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 market, based on the allowed network-safe limit.

The developing peer-to-peer innovation with electric mobility model has a higher level of digitalisation than the other industrial organisation models. For example, advanced peer-to-peer trading technologies and communication signals (digitalisation) could support power flow to and from electric vehicles with a high level of decentralised power generation and renewable energy sources to facilitate decarbonisation. This innovation could help to jointly decarbonise the power and transport sectors.

2.2 Building a sector coupling paradigm

There is an ongoing paradigm shift of the electric utilities' industrial organisation model from Models 1, 2, 3 and 4 to gradually include features of peer-to-peer innovation with electric mobility model in developing countries (see Figure 2). We coin the transformation of the electric utilities' industrial organisation as Model 1+, Model 2+, Model 3+ and Model 4+.

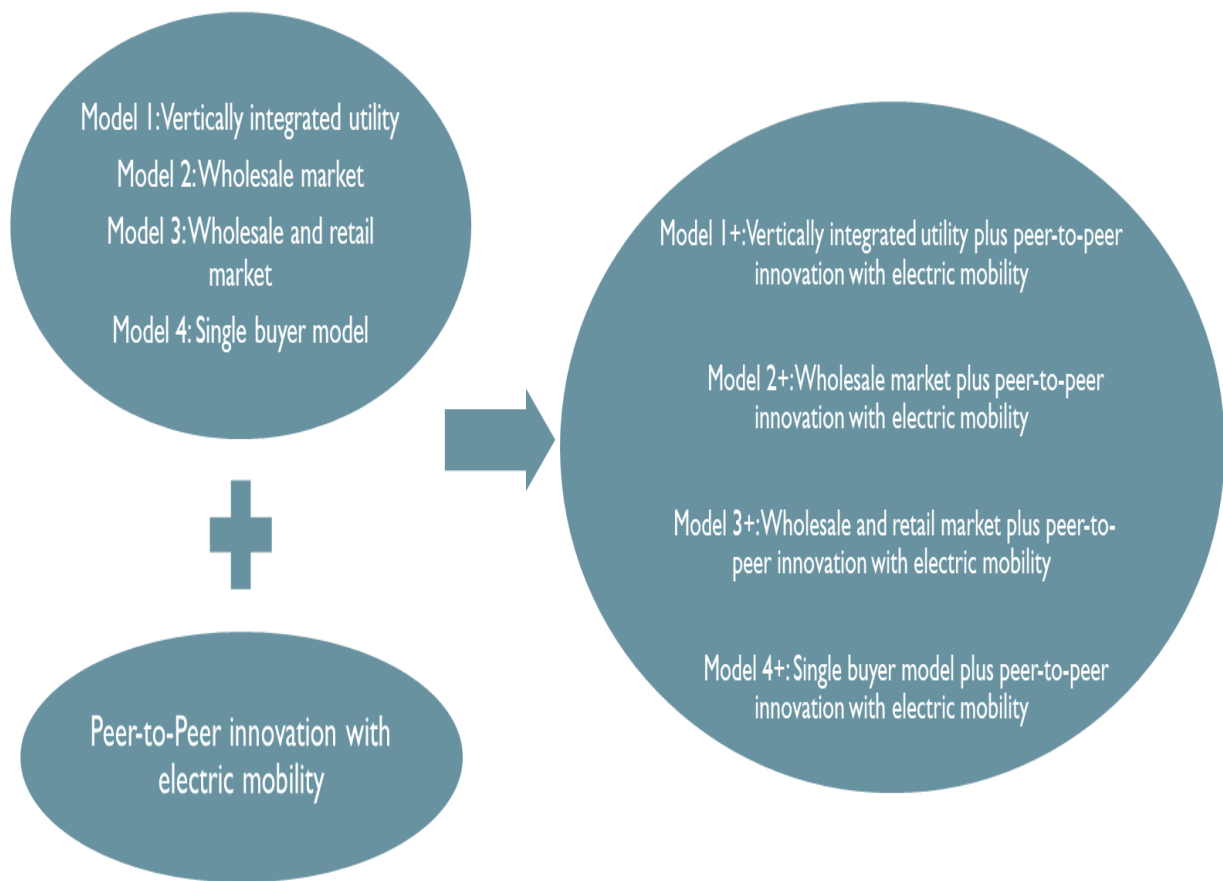


Figure 2: Utilities transformation by the peer-to-peer innovation with electric mobility

Building upon the preceding analysis, we present our 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.

In Table 1, we hypothesise the relationship between our proposed electric utilities industrial organisation models and how each model could be impacted by decarbonisation and digitalisation. Then, we use the framework to identify and classify 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 transformation of electric utilities with electric mobility (see the introduction section on pages 2 and 3) caused by the impact of decarbonisation and digitalisation is expected to be 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.

Most countries in Sub-Saharan Africa appear to fall in the Model 1+ category. For example, vehicle-to-grid, peer-to-peer trading, and aggregator business models are not topical issues of electric utilities in Sub-Saharan Africa (SSA). The availability of electric mobility and access to charging infrastructure are still low in SSA. Moreover, peer-to-peer energy trading and aggregator business models are not topical issues in SSA's power and transport sectors. The topical issues include investment in electricity access, curtailing transmission and distribution losses, curtailing non-technical losses or theft, addressing the financial viability of electric utilities, system interruption or blackouts mitigation, and addressing institutional design issues. Thus, 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 with electric mobility (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. First, we use data from the works of Foster et al. (2017). The authors analyse power sector reforms in 88 developing countries and provide an overview of each country's adoption of the standard reform model. Furthermore, Foster and Rana (2020) built upon 27 papers in the World Bank's Policy Research Working Paper series to provide

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 the market structure, private sector participation, regulatory autonomy and operational organisation. These literatures provide data and insights for classifying developing countries and case selection.

We hypothesise that developing countries in our Model 2+ and 3+ could be potential investment destinations. We list (see Table 2) the developing countries in the Model 2+ and Model 3+ classifications in our framework.

Table 2: List of developing countries in Model 2+ and 3+.(in bold the selected countries)

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, the Philippines .

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

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. Based on this framework, we select Argentina, Poland, Romania, and the Philippines to explore the lessons our analyses can offer.

3. Country case studies

In this section, we apply our framework for country case studies. The case studies aim to provide insight into whether our framework could apply to the power and electric mobility contexts in the identified developing countries. We analyse four countries in the Model 2+ and Model 3+ classifications. This selection allows us to broadly cover regional differences while addressing country-specific local challenges. Our previous study analysed case studies of Chile, Brazil, Colombia, Türkiye, India and China. Depending on data availability, we will analyse the remaining five countries and perform cross-country analyses in our future study.

3.1 The Philippines

We classify the Philippines as a Model 3+ country with a wholesale and retail power market plus peer-to-peer innovation with electric mobility in our framework. In the early 2000s, the Philippine government unbundled the power sector and allowed private sector participation in all activities in the generation, transmission, distribution, and supply through the legislation of

the Electric Power Industry Reform Act (EPIRA Act) of 2001 (Mouton, 2015; Bacon, 2019). The transmission company was privatised in 2003 through a concession agreement. The reforms had less impact on the distribution segment since the main distribution entity (MERALCO²) was privately owned. Notably, this mixed public-private ownership at the start of reform in the Philippines is uncommon among developing countries. The Philippines now has two major wholesale electricity spot markets (Luzon and Visayas³) comprising privatised generation plants (Mouton, 2015). The planned steps of the reform process incorporate private participation and competition at the wholesale and retail levels, distribution network access, and the start of retail competition (Poquiz, 2015; Bacon, 2019). Retail competition is available to large customers, although MERALCO still dominates the market for residential and small commercial groups of retail customers (Ali et al., 2022; Aris et al., 2020).

The transport sector represents a significant source of emissions in the Philippines. Emissions from the transport sector are 23% of the total emissions (Sunio and Mendejar, 2022). The Philippines' plan to reach carbon neutrality could support its power and transport sector decarbonisation and digitalisation. Thus, policies for transport sector decarbonisation are critical to achieving net zero emission objectives. The comprehensive Roadmap for the Electric Vehicle Industry (CREVI) contains the government's roadmap for developing the electric mobility industry. CREVI provides specific targets and activities to ensure a sustainable transition to an electrified transport sector, which also contributes to achieving the Nationally Determined Contributions (NDC), and ensuring energy security in the Philippines. Some goals of CREVI include increasing the utilisation of electric mobility in the domestic market and deploying charging infrastructure across the country between 2023 and 2040. CREVI provides a clean energy scenario timeline for electric mobility: ten percent of EV share of the total fleet by 2040 in households, tricycle/motorcycle should be fifty percent of EV share by 2030, cars should be twenty-five percent of EV share by 2030, and buses should be ten percent of EV share by 2030 (CREVI, 2023).

Notably, the number of electric mobility is increasing in the Philippines. For example, registered EVs have steadily risen from 145 in 2014 to 8,593 as of 2021. Following the government's support and fiscal incentives for electric mobility, electric jeepneys and tricycles are now traversing the roads of some metropolitan areas (Rosellon, 2021). Moreover, there is a growing increase in the local manufacturing and assembly of 4-wheeled electric vehicles (electric jeepneys) for the domestic market. Furthermore, the Philippines has set specific targets for

² MERALCO means Manila Electric Company.

³ Luzon and Visayas are two of the most populous islands in the Philippines

decarbonising its bus fleets (IEA, 2024). With the government's demand generation initiatives and targeted manufacturing incentives through the Electric Vehicle Incentive Strategy (EVIS) and other policy support schemes to stimulate demand and supply, the Philippines' electric mobility industry could transform into a robust and globally competitive sector and become investors' delight.

Besides, the government-supported public utility vehicle modernisation program (PUVMP) to replace ICEV with electric mobility is progressing and provides policy support for transport electrification and environmental sustainability (Guno, 2021; Gaspay and Salison, 2024; Rosellon, 2021). It is hoped that a robust legislative and regulatory framework that supports electric mobility will help drive electric mobility uptake and industrial developments and attract investments (SUM4ALL, 2021).

Regarding digitalisation, public transport operators anticipate transitioning electric mobility, such as electric jeepneys, from manual to automated fare collection systems. Automated fare collection could help minimise technical hitches in fare computation and support customer adaptation. Solutions are being proposed to integrate the transit access pass-loading process with digital platforms to streamline and encourage automated fare-collection system usage (Gaspay and Salison, 2024). An automated fare collection system enabled by digital technologies could support a hitch-free payment system, facilitate transactions, replace cash and paper tickets, and optimise operators' efficient revenue collections (Durand et al., 2023). Digital technologies could also support efficient information exchange between transport users and operators (Yigitcanlar et al., 2024). As the market further develops, the impact of electric mobility on the power grid and the need for digital technologies will become increasingly notable. For example, the charging infrastructure, power requirement and the investment implications of integrating thousands of electric jeepneys into the grid will require careful planning that can be supported by smart charging in the coming years.

3.2 Argentina

With the passing of the Energy Act in 1992, Argentina established a competitive and deregulated electricity sector with wholesale and retail competition (Irastorza et al., 2021). The power reform between 1992 and 1995 unbundled the generation, transmission, and distribution sectors (Nagayama and Kashiwagi, 2007). Argentina has retail market competition and a fully vertically unbundled market structure (De Halleux et al., 2020). The ownership unbundling of the generation sector was accompanied by creating a wholesale electricity market that allows consumers with peak demands above 30 kW to choose their preferred

supplier among retail competitors (Pollitt, 2008). Thus, we classify Argentina as a Model 3+ country with a wholesale and retail power market plus peer-to-peer innovation with electric mobility in our framework.

Electric mobility in Argentina is driven by the need to decarbonise the transport systems (Filho et al., 2022). The transport sector accounted for 14 percent of Argentina's total GHG emissions or 27 percent of energy-related GHG emissions in 2021 (World Bank, 2023b). In the Metropolitan Region of Buenos Aires, more than 90% of CO₂ emissions from the transport sector are from road transport. The government aims to reduce CO₂ and local pollutant emissions by incorporating cleaner technologies into the bus fleet. For example, the national government aims to electrify around 30% of the bus fleet by 2030. In 2018, Buenos Aires City announced a Clean Mobility Plan. The Clean Mobility Plan is the main planning framework for policies linked to transport decarbonisation and reduced local pollutants. The two main emission objectives set out in the plan include reducing CO₂ emissions by 14% and 50% of NO_x and PM from 2015 to 2035. Regarding reducing 50% of NO_x and PM emissions, the plan includes a policy mix that integrates measures for increasing shared mobility, shifting towards more sustainable modes such as public transport, and improving energy technology of vehicles through promoting the use of cleaner technologies for private and utility vehicles, buses, and taxis. Cleaner vehicles are expected to contribute 8% to CO₂ emission reductions between 2015 and 2035. Electric mobility pilot projects for electric buses are ongoing, following the government's policy support (Blanco et al., 2022).

Moreover, there are national and subnational regulations in progress, such as the Promotion of Sustainable Mobility Bill, Executive Order 331/2017, Executive Order 51 of January 2018, and the ministerial plan for the transport sector to promote the use of electric buses so they could represent 30% of the Metro area of Buenos Aires (MABA's) bus fleet by 2030. At the sub-national level, the province of Santa Fe passed Law No. 13,781, promoting the production of electric vehicles and their components in the province with incentives (Dulcich et al., 2022). Notably, there is steady growth in the electric mobility market in Argentina. In 2019, 1,548 EVs were licensed in the country, increasing to 2,383 in 2020 (Dulcich et al., 2022), 5,900 in 2021 and 7,848 units in 2022 (World Bank, 2023a). However, it is worth noting that the different government initiatives (such as the "Bill for the Promotion of Sustainable Mobility") have not yet been approved by the National Congress (World Bank, 2023a).

Given the nascent state of the electric mobility market in Argentina, digitalisation does not seem to be at the forefront of issues being considered in electric mobility. Nonetheless, it is

expected to gain increased attention as the market develops and power demand from electric mobility increases. For example, if 30% of the public bus fleet is successfully electrified by 2030, the impact of the power demand on the power grid will be topical, and the contribution of digital technologies to support smart charging and load balancing would need to be considered carefully.

3.3 Romania

The Romanian energy market opened to competition, and the wholesale market commenced operation in 2000. The vertically integrated, state-owned monopoly was divided into five separate state-owned enterprises. Since 2005, all industrial consumers have been eligible to change their supplier in the retail market, and the market became fully open in 2007. The retail market comprises a regulated market, on which the distribution companies supply energy to the captive consumers based on prices determined by the regulator and a competitive market, where contracts are negotiated between the authorised suppliers and the eligible consumers (Diaconu et al., 2009; Popovici, 2011). The retail market structure in Romania appears to align with the liberalised free market paradigm with many market participants, comparable cost structures, and there seems to be no apparent market dominance by any market participant. From 2015, household consumers can also exercise the right to change their energy supplier (Haar and Marinescu, 2011). Thus, we classify Romania as a Model 3+ country with a wholesale and retail power market plus peer-to-peer innovation with electric mobility in our framework.

Romania's objective to achieve carbon neutrality could contribute to its power and transport sector decarbonisation and digitalisation. The transport sector represents a significant source of emissions in Romania. Therefore, policies for transport sector decarbonisation are critical to achieving carbon neutrality objectives. Electric mobility for transport electrification is steadily growing in Romania. In 2020, more than 3,659 electric vehicles were sold, 8893 in 2021, and over 15,000 in 2022, and the numbers are expected to continue increasing. Also, the number of charging stations reached 441 in January 2020, over 1000 in 2021, and 1350 in 2022. Consistent with other Model 3+ countries, government policy support has been instrumental to the growth of electric mobility through fiscal incentives, public procurement programs and emission standard regulations.

Moreover, some programs funded by the Environment Fund (Emergency Ordinance No. 196 of December 2005) were promoted to reduce greenhouse gas emissions in transport activities. The objective is to promote clean and energy-efficient road transport vehicles, provide

infrastructure for clean and energy-efficient vehicles, improve air quality, and reduce greenhouse gas emissions by using fewer polluting vehicles in local public passenger transport. Other policy initiatives are Government Decision No. 739 of October 2016 on the National Climate Change Strategy based on Low Carbon Emissions and the National Action Plan for implementing this strategy (Popa et al., 2020). The government (amended Order No. 598 of March 2024 for energy-efficient road transport vehicles, 2020-2024) also offers subsidies for electric vehicles through the Rabla Classic and Rabla Plus programs (AFM, 2024).

Given the current state of the Romanian electric mobility market, digitalisation initiatives are expected to increase in the coming years. It is anticipated to gain increased attention as the market further develops and power demand from electric mobility increases. Smart charging and smart metering initiatives could be pivotal areas that would first be impacted by digitalisation as the electric mobility market further develops in Romania.

3.4 Poland

Poland is one of the developing countries that adopted power market reform. Before 1990, the Polish electricity industry was organised into five vertically integrated regional utilities. In 1990, the regional utilities were divided into 32 generation, one transmission, and 33 distribution enterprises. The Polish Power Grid Company was established in 1990, while the distribution and generation companies were privatised in 1993 and 1994. The generation, transmission and distribution of electricity became separate segments. Moreover, the Polish Power Exchange started operation in 2000 as a voluntary pool market (Streimikiene and Siksnyte, 2014). Thus, we classify Poland as a Model 2+ country with a wholesale electricity market plus peer-to-peer innovation with electric mobility in our framework.

Poland is Europe's most polluting country and highly depends on coal for energy production (Lis and Szymanowski, 2022). In some Polish cities, 60-80% of emissions are from road transport. Also, 33 out of 50 EU cities with the highest PM_{2.5} concentrations are in Poland (Sendek-Matysiak, 2021). Although electric mobility is still a relatively small share of the automotive market in Poland (Sendek-Matysiak and Łosiewicz, 2021), consumers have positive opinions about electric mobility (Bienias et al., 2020). The development of electric mobility in Poland is increasing, which is reflected in the growing sales of electric vehicles. In 2019, there were 216 electric buses and 12,475 electric vehicles in Polish cities. The number of electric vehicles was 18,875 at the end of 2020 (Łuszczuk et al., 2021). The upward trend

also continued in 2022. At the end of the second quarter of 2022, the fleet of electric vehicles increased to 50,990 units (Pokorska, 2023).

The government's policy support mechanisms through the Act of 11 January 2018 on electric mobility and alternative fuels, which implements the provisions of the Directive on the development of alternative fuels infrastructure, supports electric mobility investment. For example, the Act mandated local government units with more than 50,000 inhabitants to have a share of zero-emission buses in their vehicle fleet: 5% from January 1, 2021, 10% from January 1, 2023, and 20% from January 1, 2025. Moreover, there is also the Strategy for Responsible Development with the Electric Mobility Development Program (Sendek-Matysiak, 2021). We expect the growing electric mobility market to manifest in the increasing implementation of digital technologies in Poland. For example, in the power system planning and operation to integrate electric mobility.

4. Discussions

The case studies of developing countries in Model 2+ and Model 3+ analysed in this paper show that ongoing electric mobility investment in these countries is primarily anchored by government policy support schemes to facilitate market development.

In the Philippines, there seems to be interest in promoting electric mobility in local production and adoption (Schröder et al., 2021). Much attention seems to be on decarbonising public transport with electric jeepneys and developing domestic electric mobility manufacturing capabilities. Nonetheless, government incentives and subsidies for electric jeepneys seem to cover only a small percentage of the cost, leaving transport operators with significant monthly repayments and interest rates from debt financing. Thus, more generous policies and incentives are required to attract private-sector investors (Gaspay and Salison, 2024). Nevertheless, it is worth noting that the Philippines shows some readiness to welcome private investments, validating the classification of the Philippines (as a Model 3+ country) in our framework and a potential investment destination.

In Argentina, there are notable government efforts to develop the electric mobility market from the demand and supply sides. However, there appears to be a lack of cohesion in government policies (Blanco et al., 2022). With a long history of domestic ICEV production in Argentina (Filho et al., 2022), transitioning to electric mobility would require coherent policies to mitigate investment risks and allay uncertainty fears. Notwithstanding these issues, Argentina could be

a worthwhile investment destination, especially for public transportation with electric buses, which appears to garner much policy attention.

Romania's steady growth in the electric mobility market is noteworthy; like other countries analysed in this paper, it is primarily driven by the government's policy support to attract private investment in electric mobility local production and charging infrastructure deployment. Notably, private sector investment in charging infrastructure deployment is growing with digitalised mobile applications to access charging stations and payment for consumers. Retailers are also investing in the charging infrastructure business and deploying charging infrastructure in partnership with electric utilities (Roland Berger, 2021). The interaction between power and transport systems is driving the development of new business models, such as retailers installing and operating charging stations (Balta-Ozkan and Dalkmann, 2024).

In Poland, there is notable growth in electric mobility, which is also primarily spurred by government policy support schemes. Nonetheless, Poland would require more policy support to encourage domestic production and stimulate demand. Undoubtedly, private sector investments would also contribute to the joint decarbonisation of Poland's transport and coal-dependent power sectors. Nevertheless, it is worth noting that Poland appears to be a promising investment destination for electric mobility with the growing acquisition of electric vehicles, especially for private use. Perhaps, investment in charging infrastructure could further accelerate the market growth as it could potentially address the chicken and egg problem. It is also possible that the market development in Poland could mirror the pattern observed in many developed EU countries. Thus, we validate the classification of Poland (a Model 2+ country) in our framework as a potential electric mobility investment destination. We summarise the insights from our analyses in Table 3.

	Electric Utilities Industrial Organisation model	Decarbonisation	Digitalisation
The Philippines	Wholesale and retail power market plus peer-to-peer innovation with electric mobility Model 3+	Decarbonisation potential with policy support	Moderate digitalisation potential in the growing market
Argentina	Wholesale and retail power market plus peer-to-peer innovation with electric mobility (Model 3+)	Decarbonisation potential with policy support	Low digitalisation potential since the market is still in its infancy
Romania	Wholesale and retail power market plus peer-to-peer innovation with electric mobility (Model 3+)	Decarbonisation potential with policy support	Moderate digitalisation potential in the growing market
Poland	Wholesale market plus peer-to-peer innovation with electric mobility (Model 2+)	Decarbonisation potential with policy support	Moderate digitalisation potential in the growing market

Table 3: Insights from case study analyses

In sum, the four countries still require substantial government policy support to provide enabling environments and send the right signals to private sector investors. In the Philippines, public-private partnership business models for electric jeepneys are burgeoning; Argentina (although still in the pilot phase) seems to focus on electric buses for public transportation, like Chile and Colombia in Latin America. Poland could grow faster in the (private) electric vehicle market, while Romania is still in its infancy in developing the electric mobility market. Much of the expected growth in Romania could also be in the (private) electric vehicle and charging infrastructure market.

Therefore, the key elements for progress in electric mobility investment in the analysed countries include investment in charging infrastructure, increasing financial incentives and subsidies, developing local manufacturing capacity, government guarantee and de-risking initiatives, and developing robust policies for decarbonising and digitalising energy and transport services. Focusing on these areas could create an investment-friendly environment for electric mobility in these countries. Besides, designing sustainable business models through public-private partnerships could also attract investment.

Regarding investment innovation, carefully designed public-private partnerships should be encouraged and adapted to the specific local contexts per country. These could offer some de-risking and boost investors' confidence in these emerging markets. Also, digital technologies could play important roles in supporting emerging business models and facilitating transactions. For example, automated fare-collection system and digital platforms to streamline and encourage automated fare-collection system usage in the Philippines, smart

charging of electric buses in Argentina as the market develops or vehicle-to-grid and vehicle-to-home applications in Romania and Poland with electric vehicles. 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 (Arowolo et al., 2024).

5. Conclusion and policy implications

Due to economic capacity constraints, many developing countries are unable to follow the path that has spurred electric mobility market development in developed countries. Attracting private sector investments remains a viable option for developing countries. In this paper, we discuss our framework on the interactions of the power and transport sector in the context of decarbonisation and digitalisation to identify some developing countries that could be considered for electric mobility private sector investments. Then, we apply our framework to case studies of the Philippines, Argentina, Romania, and Poland. We find that the four countries with wholesale power markets and wholesale and retail power markets analysed in this paper could attract electric mobility investment, albeit in different segments: public transport (electric jeepneys and electric buses in the Philippines and Argentina, respectively) and (private) electric vehicles in Poland and Romania.

Based on our insights and analyses, we offer the following takeaways for stakeholders interested in electric mobility investment issues in developing countries:

Developing countries with wholesale power markets and wholesale and retail power markets could be viable electric mobility private sector investment destinations. Electric mobility investments are steadily growing in these countries. Supporting our previous research, we further validate our framework in this paper. However, the country-specific contexts and policy interest for market development solutions vary per country. For example, focus on public transport in Argentina, and the Philippines with electric buses and jeepneys, and the growing private electric vehicle market in Romania and Poland. In developing countries with wholesale power markets and wholesale and retail power markets, there seem to be notable government policy support instruments for electric mobility investment. While some countries analysed in this paper are still in their infancy in terms of market development, there seems to be a predictable growth trajectory. Moreover, these countries have developed power systems that could support them in managing the power demand and supply dynamics of electric mobility when integrated into the power grid on a large scale.

- Key takeaways for the government

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. The Philippines, Argentina, Romania, and Poland would need more robust regulatory frameworks to make considerable progress in attracting private-sector electric mobility investment in areas such as financial incentives and subsidies, developing local manufacturing capacity, government guarantee and investment de-risking initiatives. Focusing on these areas could create an investment-friendly environment for electric mobility in these countries.

Public policy support and incentives for capital cost and availability of charging infrastructure remain crucial for supporting electric mobility acquisition in developing countries. This requirement is consistent for the Philippines, Argentina, Romania, and Poland. These should be prioritised in the government's budget rather than relying on conditional facilities from development institutions or international aid.

Local capacity building is crucial for market growth. Support from the government, in terms of local capacity building for a skilled workforce and development of local manufacturing capacity and infrastructure, would help reduce investment costs, establish an investor-friendly environment, and overcome some market development challenges.

- Key takeaways for industry

Sustainable business models for electric mobility private sector investment in developing countries are required. The business models would have to be adapted to the specific local context of the countries. For example, public transport in Argentina and the Philippines or charging infrastructure in Romania or Poland. Industrial players could also take advantage of public-private partnership initiatives to get involved in the electric mobility market in the Philippines, Argentina, Romania, and Poland. Furthermore, industrial players could invest in new business models, such as installing and operating electric mobility charging infrastructure.

- Key takeaways for electric utilities, transport industries and planners

Electric utilities, transport industries and planners in Argentina, the Philippines, Romania and Poland should be prepared for upcoming changes in their modus operandi as a result of electric mobility growth in their countries. They should get involved in the coordinated and integrated planning of electric mobility charging infrastructure deployment and invest in understanding smart charging because electric mobility growth could have an impact on the

power availability from the electric grid, which has both technical and economic (investment) implications. Furthermore, electric utilities, transport industries and planners should collaborate with other business-relevant stakeholders and regulatory authorities to unlock the potential of electric mobility investments in the countries and prepare to harness the opportunities and confront challenges for the power and transport sectors as electric mobility investment grows in their countries. With this approach, a mutually beneficial relationship can be established between the power and transport sector actors. The positive effects will impact stakeholders and citizens who will benefit from decarbonised and digitised transport and energy system services from electric mobility investments.

A future research direction is to 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. Therefore, the attempt in this paper is not exhaustive.

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Data Availability

Data will be made available upon request.

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