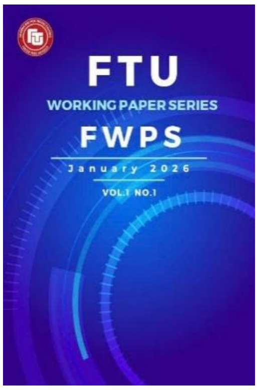

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NGHIÊN CỨU CÁC RÀO CẢN TRONG TRIỂN KHAI XE BUÝT ĐIỆN Ở HÀ NỘI: PHƯƠNG PHÁP CASE STUDY

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Tóm tắt

Nghiên cứu này phân tích quá trình chuyển đổi sang giao thông công cộng chạy điện qua hai trường hợp tiêu biểu – Thâm Quyến (Trung Quốc) và Santiago (Chile) – nhằm rút ra khung chính sách và bài học cho Hà Nội, Việt Nam. Bằng phương pháp định tính so sánh, nghiên cứu xem xét cách các thành phố giải quyết những rào cản như chi phí đầu tư cao, hạn chế nguồn cung xe, thách thức vận hành và thiếu hạ tầng sạc. Thâm Quyến đại diện cho mô hình nhà nước dẫn dắt, dựa vào trợ cấp mạnh và quy hoạch tập trung, trong khi Santiago áp dụng mô hình hợp tác công – tư (PPP), huy động vốn quốc tế và cơ chế thanh toán linh hoạt để giảm rủi ro mà

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không cần trợ cấp lớn. Dù khác biệt, cả hai đều nhấn mạnh tầm quan trọng của việc tách biệt sở hữu và vận hành, hợp tác với ngành điện, cùng tiêu chuẩn hóa kỹ thuật để mở rộng quy mô. Từ đó, nghiên cứu khuyến nghị Hà Nội kết hợp sản xuất nội địa với hợp tác quốc tế, áp dụng mô hình PPP, và phát triển hệ thống sạc gắn với nâng cấp lưới điện nhằm xây dựng hệ sinh thái xe buýt điện bền vững.

Từ khóa: xe buýt điện, Thâm Quyến, Santiago, Hà Nội, điện hóa giao thông công cộng

INVESTIGATING BARRIERS TO ELECTRIC BUS ADOPTION IN HANOI: CASE STUDY APPROACH

Abstract

This study analyzes the electrification of public transport through two leading cases - Shenzhen (China) and Santiago (Chile) - to identify effective policy frameworks and lessons for Hanoi, Vietnam. Using a comparative qualitative approach, the research examines how each city addressed key barriers such as high upfront costs, limited vehicle supply, operational feasibility, and charging infrastructure. Shenzhen illustrates a state-led model characterized by strong subsidies, centralized planning, and domestic manufacturing capacity, while Santiago demonstrates a public-private partnership model leveraging international finance, long-term contracts, and gross-cost payment schemes to minimize risks without heavy subsidies. Despite their differences, both cases emphasize the importance of asset-service unbundling, collaboration with electricity providers, and standardized technical frameworks for scalability. Drawing from these insights, the study recommends that Hanoi combine domestic production capacity with international partnerships, apply PPP-based financial models, and integrate depot-based charging with grid upgrades to build a reliable and financially sustainable e-bus ecosystem.

Keywords: electric buses, Shenzhen, Santiago, Hanoi, public transport electrification

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1. Introduction

1.1. Rationale of the study

Urban transport plays an essential role in sustainable development. The increasing level of urbanization and motorization has caused congestion, air pollution, and greenhouse gas emissions in major cities. To achieve decarbonization targets, the electrification of public transport, especially bus fleets, has become a key solution (ESCAP, 2023b; World Bank, 2020).

In Hanoi, the public transport system still faces limitations in infrastructure, technology, and investment resources. Although pilot programs such as VinBus have been implemented, the expansion of electric buses remains slow due to financial and institutional barriers. Therefore, studying international experiences from successful cities such as Shenzhen (China) and Santiago (Chile) is essential to provide practical lessons for Hanoi's transition toward sustainable mobility.

1.2. Literature review

Research on the transition to electric buses (e-buses) can be broadly categorized into two main groups: (1) literature and policy-focused studies and (2) empirical and case study research.

1.2.1. Literature and policy-focused studies

This group emphasizes theoretical frameworks, literature synthesis, and policy recommendations, providing a foundation for sustainable urban transport development. *Lã Việt Phương & Nguyễn Minh Hoàng (2023)* examine global EV transition challenges using life-cycle assessment (LCA) and secondary data, noting that while EVs reduce emissions, improve air quality, and save energy, they face barriers such as high battery costs, insufficient charging infrastructure, and reliance on coal-based grids. *ESCAP (2023)* offers a comprehensive policy guide for e-bus adoption in the Asia–Pacific region, highlighting the importance of subsidies, technology standardization, and public–private partnerships (PPP), with lessons from China, India, and Korea showing that strong national strategies and infrastructure investment are crucial for success. In Vietnam, *Hà Thanh Tùng (2022)* analyzes the potential for e-bus deployment in Hanoi using SWOT analysis and secondary data, identifying opportunities from high demand, private investment, and policy support, alongside challenges including high upfront costs, fragmented charging systems, and unstable subsidies.

Despite these contributions, most literature in this group relies on secondary data or theoretical analysis, providing limited empirical insights. Specifically, the Vietnamese context remains underexplored, and there is a lack of evidence on how policy frameworks and strategic recommendations can be effectively applied to cities like Hanoi, where financial constraints, evolving policies, and infrastructure fragmentation present unique challenges. Addressing this gap is essential for developing context-specific guidance that extends beyond general global models.

1.2.2. Empirical and case study research

This group focuses on real-world operational data, evaluating environmental, socio-economic, and technical aspects of e-bus deployment. *Lobo, Denes-Santos & Ricardo (2025)* study e-bus adoption in Brazil using Analytical Hierarchy Process (AHP) and stakeholder interviews, demonstrating that public policy is more decisive than technical factors, and highlighting the comprehensive benefits of e-buses. In Santiago of Chile, *Galarza (2020)* and *World Bank (2020)* analyze the transition from pilot projects to large-scale deployment, combining operational, financial, and emission data with stakeholder interviews. Their findings show significant reductions in CO_2, NO_x, and PM2.5 emissions and improved passenger satisfaction, while noting challenges related to charging infrastructure, subsidy dependence, and long-term operational costs. Research in Shenzhen, *Berlin, Zhang & Chen (2020)* and *World Bank (2021)*, covering over 6,000 e-buses, underscores the role of government subsidies, industry collaboration, extensive charging infrastructure, and digital management systems, while highlighting concerns about long-term financial sustainability and replicability in other contexts.

Although these empirical studies provide rich evidence from cities such as Santiago and Shenzhen, their focus on large-scale, well-resourced, high-income urban contexts limits their applicability to Hanoi. Vietnam's early-stage adoption of e-buses, coupled with constrained financial capacity, fragmented infrastructure planning, and evolving policy frameworks, means that insights from these international cases cannot be directly transferred. Therefore, research is needed to examine how lessons from global experiences can be adapted to support the practical deployment of sustainable and socially inclusive e-bus systems in Hanoi.

1.3. Research objectives

The study aims to examine international experiences in electric bus adoption to identify lessons applicable to Hanoi's transition toward sustainable public transport.

Main objective:

To analyze how Shenzhen and Santiago addressed key barriers to e-bus adoption and extract insights for Hanoi.

Specific objectives:

1. Review global frameworks for e-bus deployment and barrier mitigation.
2. Compare success factors and outcomes from Shenzhen and Santiago.
3. Assess how these lessons can be contextualized for Hanoi's policy and infrastructure.
4. Propose actionable recommendations to accelerate Hanoi's e-bus transition.

1.4. Research significance

This study makes both theoretical and practical contributions to sustainable urban transport.

Theoretically, it offers an updated overview of global barriers to e-bus adoption and contextualizes them within Hanoi's financial, infrastructural, and policy constraints, advancing understanding of how international lessons can be adapted to Vietnam.

Practically, it provides a scientific basis for policymakers, operators and other stakeholders to design more effective, risk-reducing strategies for large-scale e-bus deployment and, at the same time, serves as a reference for other Vietnamese and Southeast Asian cities in their green transport transitions

2. Theoretical framework and Methodology

2.1. Theoretical framework

2.1.1. Sustainable urban transport and e-bus adoption

Sustainable urban transport originates from the principle of meeting current mobility needs without compromising future generations' ability to meet theirs (UN, 1987; Banister, 2008). It integrates environmental protection, economic efficiency, and social equity.

E-buses are increasingly recognized as a cornerstone of sustainable transport, eliminating tailpipe emissions, reducing operational costs, and contributing to climate goals when powered by renewable electricity (Sims et al., 2014; Shinde et al., 2025). They represent a practical step toward "more sustainable" transport by substituting polluting technologies with cleaner ones (Banister, 2008).

The successful deployment of e-buses requires integrated policies linking vehicle technology, charging infrastructure, power grid management, and urban planning (Steg & Gifford, 2005). From a systems-based perspective, e-bus adoption exemplifies the socio-technical transition process, requiring alignment between innovation, institutions, and user behavior. Thus, e-buses are not only technological assets but also instruments for advancing sustainable mobility, energy transition, and urban resilience.

2.1.2. Key barriers to e-bus adoption

The preceding discussion highlights that, while e-buses are widely acknowledged as a critical component of sustainable urban transport, their adoption remains uneven due to multiple interrelated challenges. Drawing on global experiences and the literature reviewed, four key barriers, cost, availability and supply, performance and convenience, and charging infrastructure, emerge as the most frequently cited and practically relevant constraints. This barrier-based framework provides a structured lens to systematically examine the obstacles affecting e-bus deployment and the interplay among technological, financial, institutional, and operational factors.

Adopting this framework for the present study is particularly justified for several reasons. First, it aligns with empirical evidence from international case studies (Shenzhen, Santiago, Brazil), allowing comparison of barriers across diverse contexts. Second, it directly addresses the research gap identified for Hanoi, where early-stage adoption is influenced by limited financial resources, fragmented infrastructure, evolving policies, and nascent institutional capacity. Finally, using a barrier-focused approach facilitates the identification of actionable strategies and policy interventions tailored to Hanoi’s unique socio-technical and urban conditions, bridging the gap between theoretical insights and practical implementation.

Despite strong policy attention, global experiences reveal persistent obstacles to scaling e-bus adoption (ESCAP, 2023b). Four major barriers are widely recognized: cost, availability and supply, performance and convenience, and charging infrastructure.

Cost barriers: Electric buses entail higher upfront costs than diesel alternatives, primarily due to expensive battery systems. Uncertainty regarding battery lifespan, depreciation, and maintenance adds financial risk (Varga & Iclodean, 2015; Åslund et al., 2025). Although Total Cost of Ownership (TCO) may be lower over time, limited subsidies and financing access hinder widespread adoption (Aldenius et al., 2022).

Availability and supply barriers: Many developing countries lack domestic EV manufacturing capacity and depend on imported buses, increasing costs and vulnerability to supply disruptions (Lobo, Denes-Santos & Ricardo, 2025). Inconsistent technical standards further complicate procurement and interoperability (World Bank, 2020).

Performance and convenience barriers: Limited driving range, long charging times, and operational reliability concerns challenge daily bus operations. Early e-bus models required frequent charging and additional standby vehicles to maintain schedules (Aldenius et al., 2022; Lin et al., 2019).

Charging infrastructure barriers: Infrastructure deficits remain the most critical constraint. E-buses require depot-based or terminal charging systems with high land and power demands. Weak inter-agency coordination, non-standardized technologies, and limited grid capacity slow network expansion (Rogge et al., 2018; Lã & Nguyễn, 2023).

These four categories form the analytical foundation for the comparative case studies in Shenzhen and Santiago, providing a structured framework for identifying strategies applicable to Hanoi's context.

2.2. Methodology

2.2.1. Methodological approach

This study uses a qualitative comparative case study approach, examining Shenzhen and Santiago to identify key barriers to Hanoi's e-bus transition. By comparing different policy and infrastructure contexts, it aims to draw practical lessons to support Hanoi's shift toward cleaner urban transport.

2.2.2. Case selection criteria

Case selection plays a crucial role in qualitative research (Seawright & Gerring, 2008). This study selects Shenzhen (China) and Santiago (Chile) based on three criteria: extreme, diverse, and most different cases, to draw relevant lessons for Hanoi's e-bus transition.

As extreme cases, Shenzhen achieved full bus electrification in 2017, while Santiago ranked second globally outside China (Sclar et al., 2019), allowing Hanoi to identify its current gap and potential roadmap. As diverse cases, their contrasting strategies: Shenzhen's rapid, government-led approach versus Santiago's gradual, PPP-based approach, all of which offer alternative pathways for Hanoi which is in a mixed policy-market context. As most different cases, they differ sharply in political systems and financial capacity, however, both achieved success, revealing core drivers that remain applicable to Hanoi.

The selection of Shenzhen and Santiago ensures both analytical depth and practical relevance, providing comparative lessons for Hanoi's sustainable public transport electrification.

2.2.3. Data collection sources

This study mainly uses secondary qualitative data, consistent with recommendations for comparative case study research where primary data collection may be constrained (Yin, 2018), which includes academic papers, government documents, industry datasets, and reports from international organizations. Data on Shenzhen, Santiago, and Hanoi are drawn from official sources, policy documents, media reports, and existing research on e-bus deployment. Relying on secondary data allows for systematic cross-city comparison, ensures feasibility and validity, and accommodates time and resource constraints, while leaving room for future studies to include primary evidence.

3. Case study analysis

3.1. Case study 1: Shenzhen - China

Shenzhen became the world's first city to achieve full public bus electrification, operating over 16,000 e-buses by 2017 (World Bank, 2021). Integrated with the metro as the backbone and supported by e-taxis accounting for 10–12% of modal share (Berlin et al., 2020), the system has helped cut emissions, improve air quality, and boost China's EV industry (Lin et al., 2019). Shenzhen Bus Group (SZBG), the largest operator, which carries roughly 40% of all passengers, became the first operator globally to electrify its entire 6,000-bus fleet, with Eastern and Western Bus Companies following the same municipal electrification framework (UN-ESCAP, 2023a). To better understand how Shenzhen overcame key barriers in e-bus adoption, this section analyzes the city's strategies for addressing high costs, limited supply, operational feasibility, and infrastructure challenges.

3.1.1. Cost barriers

High upfront investment constituted the most significant barrier to Shenzhen's e-bus transition. Even as prices gradually declined since 2009, electric buses remained nearly twice as expensive as diesel models, while batteries and charging facilities, including land, equipment, and grid connections, added further financial burdens for operators (World Bank, 2021; IEA, 2020). Early uncertainty regarding battery lifespan and maintenance intensified the cost–risk profile associated with electrification.

To mitigate financial risks, Shenzhen implemented innovative financial leasing models supported by strong government subsidies. The bus–battery separation model (2011–2013) transferred battery ownership to a state-owned Potevio Group Corporation, while the bus bodies were purchased by a financial leasing company and then leased to SZBG. This model reduced SZBG's financial and operational risks since batteries at the time were prone to failures and not yet covered by OEM warranties (World Bank, 2021).

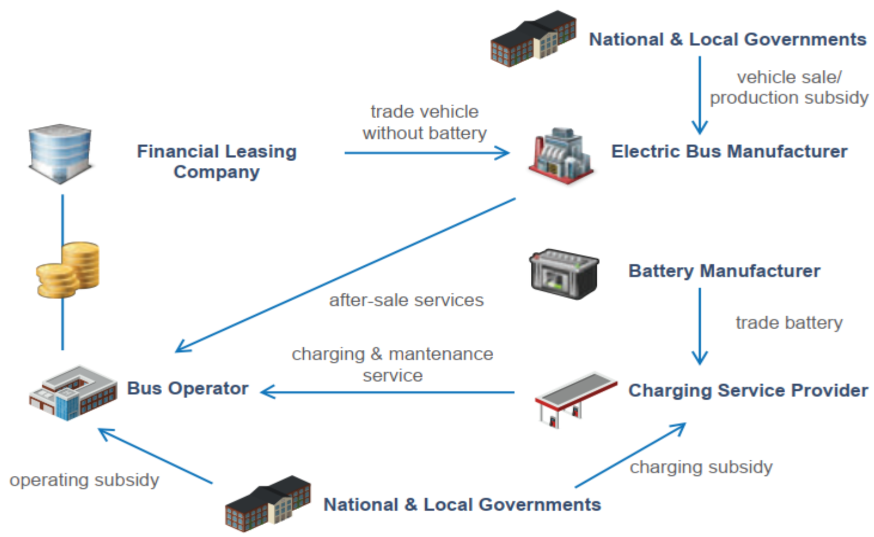

Figure 1. Bus - Battery Seperation Financial Leasing Model

Sources: World Bank (2021)

As technology improved, Shenzhen shifted to whole-vehicle leasing (from 2015), with leasing companies purchasing and owning buses for their eight-year lifespan. This converted high CAPEX into stable OPEX through long-term leases, while lifetime warranties on key components reduced maintenance risks (World Bank, 2021). Charging infrastructure was owned by service providers, allowing for clear risk allocation and efficient operation (World Bank, 2021).

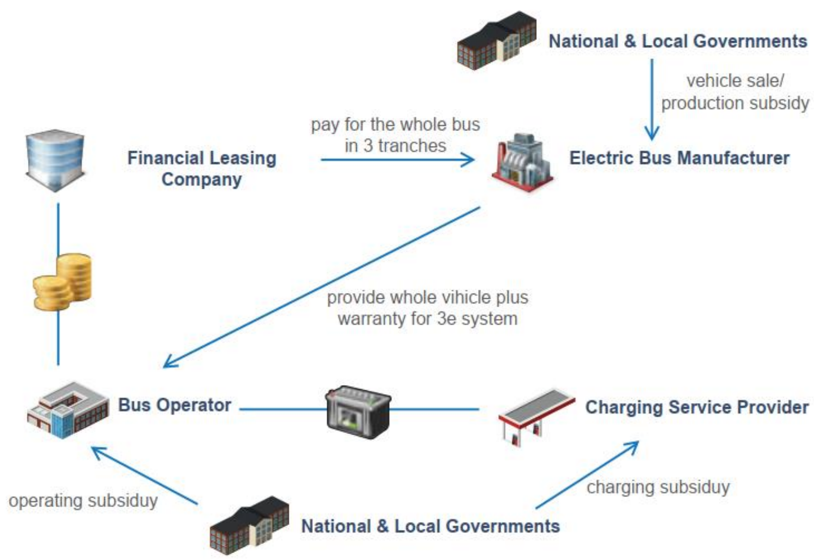

Figure 2. Whole - Vehicle Lease Financial Leasing Model

Sources: World Bank (2021)

At the same time, the Chinese government introduced a multi-level subsidy policy that reduced the cost burden for manufacturers, operators, and infrastructure providers. National and municipal subsidies jointly covered more than 60% of bus purchase costs during 2015–2017, while operational subsidies for e-buses far exceeded those for diesel buses, covering up to 87% of total operational expenses (Alstom, 2018). These combined financial and policy measures significantly lowered cost barriers and made e-bus operations economically feasible.

3.1.2. Availability and supply barriers

In the early stages (2009–2012), Shenzhen faced challenges in securing a stable supply of electric buses and components: limited OEMs, immature technologies, and fragmented technical standards constrained the availability of electric buses. These limitations created risks in vehicle selection and maintenance, delaying large-scale deployment (World Bank, 2021). This illustrates that supply-side limitations can act as a structural barrier, affecting both operational feasibility and strategic decision-making in urban electrification projects.

To ensure supply stability and encourage OEMs to expand production capacity, Shenzhen adopted a tripartite coordination model. First, large-scale procurement and long-term contracts provided stable demand, incentivizing OEMs to expand production and reduce costs (World Bank, 2021). Second, mandatory technical standards improved product quality and ensured compatibility across suppliers, which reduced uncertainty, facilitated mass production, and ensured compatibility across suppliers (World Bank, 2021). Third, institutional coordination through Shenzhen Energy Conservation and New Energy Vehicle Demonstration and Promotion Leading Group (SNEVLG) in 2009 enabled aligned policy implementation and infrastructure planning, showing that overcoming supply constraints requires inter-agency collaboration beyond technical fixes. Through these integrated efforts, Shenzhen successfully secured sufficient supply to electrify 100% of its bus fleet by 2017, providing a replicable model for global cities.

3.1.3. Barriers in terms of range, convenience, and reliability

Operational feasibility was another major challenge in Shenzhen's e-bus transition. Early models, such as the BYD K9, had limited range and required frequent charging, reducing route flexibility and operational convenience. Battery durability issues further constrained reliability, highlighting that technical limitations can create systemic operational barriers that affect fleet planning, scheduling, and cost-effectiveness.

To address these challenges, Shenzhen adopted a phased implementation strategy combined with technical and operational adaptations. Small-scale pilots (2012-2015) allowed real-world performance data collection and informed improvements, such as the BYD K8 with extended range, higher energy efficiency, and flexible DC fast charging (World Bank, 2021). Operational measures that optimized scheduling, State of Charge (SOC) management, and driver retraining - further ensured that buses met daily route demands while maintaining safety and reliability (Lin et al., 2019). For reliability, SZBG used the battery - bus ownership separation model, which reduced costs and enabled battery replacement without retiring vehicles (Li et al., 2018). This approach shows that addressing reliability barriers requires not only technological upgrades but also institutional and financial mechanisms that distribute risk and responsibility.

3.1.4. Charging infrastructure barriers

A major challenge during the electrification process was developing and managing adequate charging infrastructure. Instead of constructing its own facilities, SZBG cooperated with specialized charging service providers to deliver charging services. This arrangement transferred land-use and maintenance risks to partners but faced limitations due to land scarcity and high power demand. Electric buses require high-capacity and location-specific charging, which posed significant spatial and grid challenges (Lin et al., 2019; Jiang et al., 2022).

To overcome infrastructure constraints, Shenzhen adopted two main strategies. First, the city introduced charging station innovations and flexible use of public land, simplified approval procedures, and the networked charging concept allowed efficient use of scarce urban space (World Bank, 2021). Second, Shenzhen addressed grid pressure through optimized charging schedules and smart energy management, distributing charging loads across different times to avoid peak-hour strain (Zhang et al., 2025). Moreover, The city transformed major depots into multi-purpose stations and introduced GB/T standard chargers, enabling different vehicle types to share infrastructure (Mao & Rodríguez, 2024). These integrated policies and technologies allowed Shenzhen to build a reliable, efficient charging network that supported its large-scale e-bus operations.

The table below summarizes the main barriers Shenzhen faced in its e-bus transition and the key solutions implemented to overcome them:

Table 1. Shenzhen case study summary

Barriers	Strategies

1. Cost barriers	High CAPEX, delayed TCO benefits	Implementing government subsidy policies and charging support
	Limited financing capacity of operators & financial risks	Innovative financial leasing models supported by strong government subsidies
2. Availability and supply barriers	Risk of supply shortage during fleet expansion	Large-scale procurement & long-term contracts to secure supply
	Fragmented technical standards	Establishment of mandatory technical standards to reduce uncertainty
	Limited governance and cross-sector coordination	Creation of the Shenzhen NEV Leading Group for cross-sector coordination
3. Range, convenience & reliability barriers	Limited range (lower than diesel)	Phased electrification strategy & technical upgrades before full roll-out
	Dependence on depot charging, SOC fluctuation	Scheduling optimization and SOC management for daily operations
	Low reliability (short battery life 4–5 years, high replacement cost)	Bus-battery separation lease and whole-vehicle lease to reduce financial and technical risks
4. Charging infrastructure barriers	Land for building charging stations in dense urban areas	Flexible use of public land and simplified approval procedures to accelerate station deployment
	High pressure on the local power grid due to peak charging demand	Optimized charging schedules and coordination with utilities to prevent grid overload

Source: Synthesized by the authors

3.2. Case study 2: Santiago – Chile

In recent years, Santiago has become a leading Latin American model for public transport electrification, tackling challenges in financing, infrastructure, supply chains, and governance since launching e-bus pilots in 2017, reaching more than 2,550 units by 2025 and targeting 4,406 buses (70% of its fleet) by year-end (Sustainable-Bus, 2025). In Santiago, the transport system is where the metro serves as the backbone and buses take on surface function, the introduction of e-bus programs enhances connectivity, expands coverage, and serves high-demand routes, thereby, reducing emissions, noise and improving overall sustainability (World Bank, 2020; ITDP, 2021).

3.2.1. Cost barriers

High upfront capital costs constituted the most immediate barrier to the adoption of electric buses in Santiago. By 2018-2019, electric buses were 45–58% more expensive than comparable diesel models, while operators lacked access to long-term credit and faced revenue structures that were incompatible with high-CAPEX investments (World Bank, 2020). Table 2 below illustrates the cost differences between diesel and electric buses.

Table 2. Comparison between diesel and electric bus in Santiago (2019)

Item	Diesel (12m)	Electric (12m)
Capital expenditure (CAPEX, cost of the bus)	\$190,000 - \$200,000	\$290,000 - \$300,000
Performance	2 km/Lt	0.9 - 1.0 km/kWh
OPEX	\$0.42/km	\$0.10/km
Maintenance cost	\$0.27/km	\$0.08/km

Source: World Bank (2020)

To overcome cost-related barriers, Santiago introduced a public–private partnership structure that separated asset ownership from service provision. Under this model, Special Purpose Vehicles led by Enel X and Engie financed buses and charging depots, while operators focused solely on service delivery under 13-14-year gross-cost contracts. This restructuring shifted financial risks away from operators, strengthened project bankability, and attracted investment from institutions such as IFC and IDB Invest. Combined with off-peak depot charging strategies that reduced electricity costs, these measures lowered total cost of ownership by roughly one-third and created a scalable financial architecture which can support rapid fleet expansion (Centro Mario Molina, 2022).

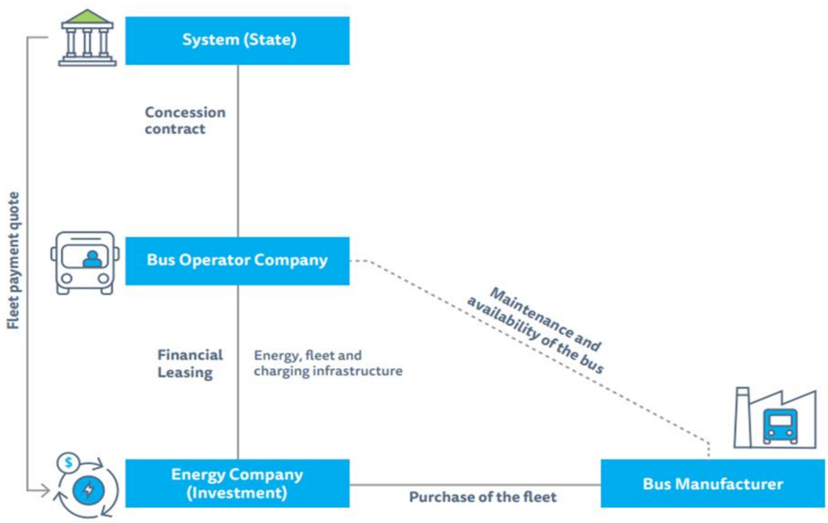

Figure 3. Organizational diagram of actors' interrelations in the PPP in Santiago

Source: World Bank (2020)

3.2.2. Availability and supply barriers

Santiago relied almost entirely on Chinese OEMs (95%), causing long delivery times, spare part delays, and "technology lock-in." Certification processes were also slow due to the absence of standardized national regulations, often requiring 12 to 18 months for homologation. (World Bank, 2020; ICCT & ZEBRA, 2021).

Santiago addressed supply and availability barriers by first using pooled procurement and open tendering to diversify suppliers and leverage economies of scale. It then deployed SPV-based financial structuring with long-term contracts, improving bankability and attracting international finance for large packages. Parallel logistics and spare-parts optimization minimized maritime delays and reduced disruption risk, while DTPM's technical standardization shortened homologation times and ensured infrastructure compatibility across fleets. These measures transformed supply availability from a technological bottleneck into a procurement and institutional coordination challenge that Santiago was able to systematically mitigate. Together, these measures enabled deployment of 992 e-buses by 2023, making Santiago Latin America's leader in e-bus scale-up (IDB Invest, 2023; IFC, 2023).

3.2.3. Barriers in terms of range, convenience, and reliability

Operational feasibility formed the third barrier to electrification. Santiago's hilly topography, intensive stop-and-go patterns, and long route profiles reduced actual battery ranges to between 250 and 400 km, far below nominal specifications of 350–400 km (World Bank, 2020). With limited fast-charging infrastructure available, the system depended heavily on depot charging, creating risks of insufficient range during peak hours and increased vulnerability to scheduling disruptions. Table 3 presents key battery performance indicators for Santiago's fleet.

Table 3. Battery's design and performance specifications

Item	Range
Autonomies	250 - 400 km
Batteries Size	290 - 350 kWh
Batteries guarantees	5-10 years/ the equivalent in number or cycles
Average consumption	0,85 - 0,95 km/kW

Sources: World Bank (2020)

To address feasibility concerns, Santiago applied an integrated approach combining overnight charging, smart load management, and phased deployment. Overnight slow charging at 15-22 over roughly 10 hours kW provided full charging at low cost (USD 0.10/km), while smart charging platforms operated by Enel X optimized load distribution and prioritized departures, maintaining fleet availability above 99% (World Bank, 2020; Galarza, 2020; Enel X, n.d.; DTPM, 2025). Early pilots in 2017-2018 collected telematics data on energy consumption, temperature variation, and state-of-charge across gradient-intensive routes, informing battery sizing, route allocation, and depot design for subsequent large-scale deployments, supported by financial mechanisms like FleetCo leasing and IFC funding (IFC, 2023). This approach shifted the feasibility challenge from one of technological limitation to one of operational and data governance, demonstrating that early-stage experimentation is essential for reducing uncertainty in large-scale transitions.

3.2.4. Charging infrastructure barriers

Santiago struggles with limited land, high costs, and weak coordination between transport authorities and electricity utilities Santiago's plan for 28 electro-terminals with an estimated grid demand of 89 MW required substantial upgrades in transmission capacity, however, unclear permitting procedures and fragmented institutional responsibilities delayed infrastructure development (World Bank, 2020; Peltier et al., 2023).

Santiago overcame charging and grid barriers through an integrated approach combining infrastructure innovation, cross-sector partnerships, and institutional reform. The city prioritized large-scale centralized depots with solar-integrated roofing and smart charging systems to save space and optimize energy use (Enel X, 2018; ICCT, 2023). It partnered with power utilities like Enel X, which co-financed buses and depots, invested in high-capacity grid connections (~USD 3 million per depot), and operated systems under 10-year leases, thereby sharing financial and technical risks (Morris, 2020). Meanwhile, institutional reforms separated bus ownership from charging infrastructure, with energy firms responsible for installation and maintenance under government-backed guarantees and long-term contracts ensuring coordination among utilities and operators (World Bank, 2020; TUMI, 2023). These measures eliminated infrastructure bottlenecks, reduced costs, enhanced grid reliability, and enabled Santiago to achieve one of Latin America's largest e-bus deployments.

The table below summarizes the main barriers Santiago faced in its e-bus transition and the key solutions implemented to overcome them:

Table 4. Santiago case study summary

Barriers		**Strategies**
1. Cost barriers	High CAPEX, delayed TCO benefits	Optimize TCO via off-peak charging and infrastructure
	Limited financing capacity & financial risks	PPP & Asset service unbundling
	Revenue & CAPEX mismatch	Long-term concession contracts
2. Availability and supply barriers	95% supply from Chinese OEMS	Competitive bidding & supplier diversification
	Complex homologation & regulation	Technical standardization & regulatory framework

	Risk of technology lock-in	SPV, long-term contracts, IFC/IDB financing
3. Range, convenience & reliability barriers	Range risk & terrain	Overnight depot charging & pin sizing
	Depot charging dependency	Smart charging & off-peak scheduling
	Operational data gap	Phased pilots & telematics data
4. Charging infrastructure barriers	Land constraint	Electro-terminals, solar roofs
	Grid connection pressure	Energy provider investment & grid coordination
	Institutional bottleneck	Public-private model, capital guarantees, long-term contracts

Source: Synthesized by the authors

3.3. Cross-case comparison

To synthesize the findings from the two case studies, Table 5 analyzes the key similarities and differences in how Shenzhen and Santiago addressed four main e-bus implementation barriers. This comparative analysis illuminates the institutional, financial, and operational mechanisms that differentiate each city's transformation trajectory.

Table 5. Comparative analysis between Shenzhen and Santiago case study

Barriers	Similarities	Differences	
		Shenzhen	**Santiago**
1. Cost barriers	• Both apply asset–service unbundling to separate ownership, operations and charging, reducing operators' CAPEX exposure.	• With strong public finances, Shenzhen provides direct subsidies across the entire value chain: to manufacturers, charging infrastructure, and operators; and has preferential electricity tariffs (World Bank, 2021).	• Due to limited fiscal capacity, Santiago uses PPP- and market-led models (World Bank, 2020). • 13–14-year gross-cost contracts stabilize revenue streams. • Heavy reliance on international finance (IFC, IDB Invest). • Cost savings achieved through contractual innovation + off-peak charging.
2. Availability and supply barriers	• Both cities use long-term contracts and technical standards to ensure stable supply and compatibility. • Both aim to reduce deployment risks and attract manufacturers.	• Shenzhen has a domestic electric vehicles industry supported by strong national policies (World Bank, 2021). • Long-term contracts → guarantee demand for EV manufacturers • National standards → market harmonization, and promotion of the domestic EV industry. → Nurturing and expanding the domestic manufacturing industry.	• Import-dependent system with no local production (World Bank, 2020). • Uses pooled procurement → better negotiation terms with manufacturers. • Logistics optimization to manage import delays/spare-parts shortages. • Standards focus on import facilitation and interoperability, not fostering domestic OEMs. → Facilitating procurement and import processes.
3. Range, convenience & reliability barriers	• Both equipped buses with batteries larger than daily distance. • Both conducted pilot projects before large-scale rollout. • Digital charging management systems used for scheduling and readiness.	• With strong subsidies and strong OEM R&D → large fast charging network for daytime operation(World Bank, 2021). • Due to local production, pilot projects, besides optimizing operations, also served as feedback loops for bus manufacturers like BYD	• Higher costs of fast charging infrastructure and lack of subsidies → limited fast-charging adoption, restricted to pilot scale (World Bank, 2020). • Limited fast charging for daytime operation → many long routes still required a mixed fleet • Pilots focus on operational optimization rather than R&D/standard-setting.

4. Charging infrastructure barriers	• Both ensure land access for depots/stations and coordination with power utilities for grid capacity. • Both aim to upgrade grids to meet future charging demand.	• Young city, integrated urban planning reserves land for multi-story depots and charging stations → have depots both in the dense area (e.g. Futian) and outskirts (Ng et al., 2020; Zhang et al., 2021). • Streamlined approval procedures for charging installations. • Mandatory charging points in new developments. • Preferential tariffs and subsidies expand a multi-layered depot + on-route charging network.	• Old city land in urban core is already fully developed, making depot construction there unfeasible due to high acquisition costs and potential conflicts of interest → depots located mainly on the periphery (Correa-Parra et al., 2023). • Centralized depots operated by private energy firms (e.g., Enel X). • No preferential fast-charging tariffs → reliance on off-peak overnight charging. • Fast-charging remains limited due to high costs and weak grid incentives.

Source: Synthesized by the authors

Conclusion:

In essence, both Shenzhen and Santiago demonstrate that similar strategic principles, including risk separation, long-term contracting, and public–private coordination, can produce distinct institutional and operational outcomes. Shenzhen's state-led, industrial policy approach leverages public fiscal strength and domestic production capacity, whereas Santiago's market-oriented, finance-driven model compensates for limited state funding through contractual and institutional innovation. These contrasting pathways emphasize the importance of aligning e-bus transition strategies with each city's financial, industrial, and spatial context.

4. Current status of Hanoi's e-bus network

4.1. Overview of Hanoi's current electric bus network

Since its first launch in December 2021, Hanoi's electric bus program has expanded steadily, with 14 operational routes by mid-2025, including 10 operated by Vingroup and 4 in partnership with other investors, totaling over 365 green buses, of which more than 240 are electric (DTiNews, 2025; Ministry of Construction, 2025). Despite this progress, e-buses represent only 19.7% of Hanoi's subsidized fleet, revealing a substantial gap toward its 2035 clean transport goal (Ministry of Construction, 2025). The city's e-bus system is transitioning toward an owner–operator model, with VinFast as vehicle manufacturer and Transerco and Bảo Yến Group as operators. V-Green, a Vingroup subsidiary, manages the fast-charging infrastructure using StarCharge 150 kW systems (VinFast, 2018; V-Green, 2024).

Hanoi's transport vision to 2065 emphasizes multimodal integration between e-buses, metro, BRT, and shared mobility, ensuring consistency with urban planning and sustainability objectives (Government of Vietnam, 2024; European Investment Bank, 2024).

4.2. Barriers to e-bus adoption in Hanoi

4.2.1. Cost barriers

High upfront investment remains the most significant challenge. Each VinBus e-bus costs approximately 7 billion VND, more than double a diesel equivalent, while battery replacement after 4–5 years adds major costs (Tuổi Trẻ News, 2023; Vietnam News, 2025). Although operating costs (OPEX) are lower, the Total Cost of Ownership (TCO) advantage emerges only after 10–15 years (Basuki, 2025). The current subsidy framework, designed for diesel and CNG buses, does not yet cover medium and small e-bus types (WRI Ross Center, 2023). Hanoi already spends 2.3 trillion VND annually subsidizing public transport and needs about 48.6 trillion VND by 2035 for full electrification (VnExpress, 2024; VietnamPlus, 2024). Incentives such as tax exemptions and 50% interest support (ICCT, 2022; Nhan Dan Online, 2024) remain insufficient, while tariff uncertainty under *Decision 14/2025/QĐ-TTg* adds long-term financial risk (Government of Vietnam, 2025; Vietnamnet, 2025).

4.2.2. Availability and supply barriers

Vietnam's limited industrial base constrains the domestic supply of electric buses. VinFast remains the only producer of large e-bus models, while medium and small vehicles still depend on imports (Le et al., 2021). The market dominance of major Chinese manufacturers such as BYD, FOTON, and YUTONG increases vulnerability to external logistics and pricing fluctuations. Although Hanoi has improved its legal and bidding frameworks, investor participation remains limited, leading to route delays and weak competition (Vietnam News, 2025). Furthermore, the supporting ecosystem for batteries, maintenance, and charging infrastructure is still in an early stage of development, restricting scalability and operational efficiency.

4.2.3. Barriers in terms of range, convenience, and reliability

VinBus models currently achieve 220–260 km per charge, shorter than the 250–350 km typical of diesel buses (People's Committee of Hanoi, 2024). This necessitates additional vehicles or mid-day fast charging, raising operational complexity (Vietnam News, 2025). Hot and humid weather and uneven terrain reduce battery life and performance (Henning et al., 2019; People's Committee of Hanoi, 2024). Moreover, limited disclosure on battery specifications and durability creates uncertainty regarding long-term reliability and maintenance costs, deterring investor confidence.

4.2.4. Charging infrastructure barriers

The rapid expansion of e-bus fleets intensifies pressure on Hanoi's power grid and land availability. EVNHanoi has confirmed short-term supply sufficiency but requires 3–5 years of grid upgrades for large-scale expansion (People's Committee of Hanoi, 2024). Current charging infrastructure, led by V-Green, includes two depots and about 113 charging points (Hanoi Times, 2024) but mainly serves one operator. Lack of interoperability limits efficient utilization (Vietnam News, 2025). Inner-city land scarcity and complex permitting further hinder new station construction (Tuổi Trẻ News, 2025). Recent regulations require 10% of parking spaces in existing facilities and 30% in new projects to have EV chargers, with incentives valid until 2033 (EVNHANOI, 2024). Nonetheless, implementation remains slow compared to the city's electrification targets, posing major obstacles to the e-bus transition.

5. Lessons learned for Hanoi

Based on Hanoi's current bus system and international lessons, several solutions are proposed to overcome existing barriers toward full electrification.

5.1. Cost barriers

Hanoi's electric bus operators such as VinBus, Transerco, and Bảo Yến currently both own and operate fleets, leading to high investment costs and limited scalability. To address this, ownership and operation should be separated through a vehicle-leasing model. A state-private joint asset company would purchase buses and lease them to operators under long-term contracts, allowing SMEs to join without heavy capital burdens. Transparent leasing formulas and an independent supervisory committee would ensure fairness and attract investors and international funds.

Operators would sign performance-based service contracts evaluated by KPIs such as punctuality and passenger satisfaction. Training and credit incentives could support SMEs.

VinFast would remain the main supplier initially, but from 2030, competitive bidding should include other manufacturers to avoid dependency and promote innovation. Cooperation between charging providers and EVNHN would enable centralized depot charging during off-peak hours, cutting electricity costs and grid pressure. Over time, depots could integrate solar and battery systems.

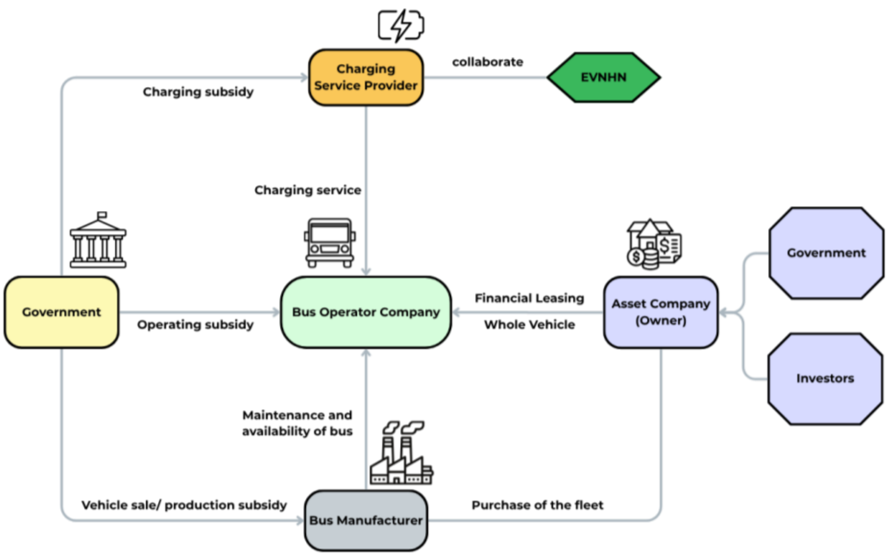

Figure 4. Proposed organizational diagram of stakeholder's interrelations for Hanoi

Source: Synthesized by the authors

This PPP model reduces CAPEX and OPEX while maintaining government oversight. Subsidies should gradually decline as market maturity grows. A transparent coordination mechanism would distribute revenues and subsidies fairly among operators, suppliers, and investors, ensuring sustainability.

5.2. Availability and supply barriers

As of 2025, Hanoi's 240 electric buses make up less than 20% of the fleet. A major gap lies in the absence of long-term procurement frameworks to ensure stable supply. Lessons from Shenzhen and Santiago show that long-term contracts are essential to secure production, attract investment, and reduce risks.

In the short term (2025-2030), Hanoi should apply the Shenzhen model, signing direct long-term contracts with VinFast that define minimum order volumes and full life-cycle services, supported by subsidies and land incentives. This strengthens domestic manufacturing and prepares for competition.

From 2030-2035, the city should shift toward the Santiago model, opening competitive bidding and encouraging private and international financing. Concession contracts of 10-12 years would allow diversified participation and lessen fiscal pressure.

Vietnam should also develop specific technical standards for electric buses and charging stations, covering battery, charging power, safety, and communication systems, to ensure product quality and enable mass production.

5.3. Barriers in terms of range, convenience, and reliability

To improve system reliability, buses must be integrated into Hanoi's overall public transport network, coordinating with metro and other modes. In the urban core, electric buses should complement metro lines for short- to medium-distance trips, reducing the need for large fleets. In suburban areas, longer routes will continue, requiring more charging facilities. Until 2030, a mixed fleet (electric with diesel/CNG) should operate to maintain service continuity, with subsidies favoring electric buses to sustain momentum. Routes should match current electric ranges (220-260 km) to avoid mid-day charging.

The city should adopt centralized off-peak charging and share operational data with regulators for monitoring and policy adjustment.

In the long term, Hanoi should expand fast-charging stations, integrate solar-powered depots with storage systems, and cautiously explore new technologies like battery swapping, building toward a stable, efficient electric bus system.

5.4. Charging infrastructure barriers

Charging infrastructure remains a major obstacle. In the short term (2025-2030), the city should reform land allocation with a "one-stop shop" process, prioritize public land near depots, and require load-balancing systems to prevent grid overloads.

By 2030-2035, large depots (100-200 buses) should be built outside the city core, with integration into the Master Plan and direct grid connections. Rooftop solar, energy storage, and fast-charging stations along key routes should be promoted. After 2035, super-depots with over 300 buses should act as integrated energy hubs using renewable power purchase agreements.

Throughout these stages, power grid upgrades must precede depot commissioning, and coordination among EVNHN, charging providers, and the asset company is vital for reliability.

6. Conclusion

6.1. Research limitations and future research

Although this research provides valuable theoretical and practical insights, several limitations remain. First, it relies mainly on secondary data from international cases (Shenzhen and Santiago) and public reports for Hanoi, which may not fully reflect local conditions. Second, limited data on battery performance, long-term reliability, and grid capacity required several assumptions that may simplify real technical and financial challenges. Third, the study is mostly qualitative and lacks quantitative models such as total cost of ownership (TCO), life-cycle assessment (LCA), and cost-benefit analysis (CBA).

Future research should collect empirical data in Hanoi through surveys with operators (Transerco, VinBus, Bao Yen), energy providers, and policymakers, along with long-term monitoring of vehicle and battery performance. Further analysis of grid capacity, charging infrastructure, and peak load management is needed. Applying quantitative models can better assess costs, benefits, and environmental impacts. Finally, studies should examine institutional and policy aspects, including PPP structures and contract models suited to Vietnam's context, while comparative research with other cities can help identify best practices for expanding e-bus adoption.

6.2. Conclusion

In conclusion, the comparative analysis of Shenzhen and Santiago underscores that there is no universal model for e-bus adoption; each city's success depends on its governance structure, financial capacity, and industrial base. Shenzhen's experience illustrates the power of state-led investment, coordinated planning, and domestic production, while Santiago demonstrates the effectiveness of leveraging private capital through innovative contractual frameworks and international financing.

For Hanoi, the pathway forward lies in designing a hybrid model that combines strong public oversight with incentives for private participation. By adopting asset–service unbundling and risk-sharing mechanisms, Hanoi can attract investment while maintaining service quality. Moreover, strategic planning for charging infrastructure and grid integration will be critical to ensuring operational efficiency and scalability. Ultimately, e-bus transition is not just a technological shift but a systemic transformation requiring coherent policies, institutional coordination, and stakeholder alignment. If Hanoi successfully adapts global best practices to its local context, it can establish a sustainable, resilient, and inclusive urban transport system that accelerates its low-carbon transition and enhances overall urban livability.

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