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ZEBRA
ZERO EMISSION BUS
RAPID-DEPLOYMENT ACCELERATOR

Charging infrastructure for zero-emission buses — Strategies in Bogotá D.C., Colombia

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This case study is part of a three part series that analyzes Bogotá's strategy as a TUMI mentor city, based on an examination of the following aspects of electric buses: technological progress (including details on pilot tests, cycles, and routes); business models (through a presentation of the innovations that have been widely implemented for managing the procurement of electric buses); and charging infrastructure. (This document describes how infrastructure and charging energy were provided, taking technical and regulatory aspects into account).

ZEBRA: The ZEBRA (Zero Emission Bus Rapid-deployment Accelerator) partnership works to accelerate the deployment of zero emission buses in Latin American cities, with the final aim to achieve climate goals, improve urban air quality, and the overall standard of public transport. ZEBRA is a ClimateWorks Foundation funded partnership led by the ICCT and C40 Cities, and supported by CMM-Chile and WRI.

TUMI E-Bus Mission: The TUMI (Transformative Urban Mobility Initiative) E-Bus Mission supports cities in their transition towards electric bus deployment. We work closely with 20 deep-dive cities in Africa, Asia and Latin America (LATAM). National and regional core groups work to upscale our efforts in a network which will include over 100 cities spread across the globe by 2022. By 2025, the TUMI E-Bus Mission will inspire and equip cities to procure more than 100,000 e-buses, resulting in a reduction of more than 15 megatons of CO2 emissions.

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INTRODUCTION: THE ZERO-EMISSION CONTEXT IN BOGOTÁ

In 2021, Colombia became the world's second-largest electric-bus market. By September 2022, it had more than 1,589 electric buses.[1] After China, which has more than 500,000 electric buses, and together with Chile, which will have an estimated 1,170 such buses by 2023, Colombia is a leader in goals and actions for the decarbonization of mass transit. The city of Bogotá D.C. is the focal point of this progress. As a mentor city of the TUMI E-Bus Mission, it aims to share the lessons of its success with other cities and countries in Latin America and worldwide.

Thanks to the Colombian energy grid, which offers a high percentage of hydroelectric power with sufficient infrastructure to meet the increased demand for zero-emission vehicles, Colombia has several national electromobility policies.[2] Their primary aim is to drive the country's progress toward decarbonization. Accordingly, they have enabled the country to acquire the largest number of electric buses in Latin America—in a region where, other than in Chile, such accomplishments have been difficult.

Colombia's public policies require the purchase of a sufficient number of electric vehicles to make up at least 30% of the mass transit fleet by 2025.[3] The requirements imposed by the national government for major cities call for a minimum purchase of electric buses, starting with 10% in 2025 and increasing gradually to 100% in 2035.

The local government in Bogotá D.C. has gone even further, banning new internal combustion buses starting in 2022 (or 2024 in certain extraordinary cases).[4] Achieving this goal will require finalization of the business models, along with the vehicle specifications and the charging infrastructure necessary for the use of the electric buses that will replace internal-combustion buses (both diesel and gas-powered).[5]

1 "Electric bus, main fleets and projects around the world," *Sustainable Bus,* January 16, 2023, https://www.sustainable-bus.com/electric-bus/electric-bus-public-transport-main-fleets-projects-around-world/; E-Bus Radar, "América Latina, accessed March 13, 2023, https://www.ebusradar.org/.

2 Ernst & Young, *"Mapa de ruta para la transición hacia vehículos de bajas y cero emisiones"* ["Roadmap for the transition to low- and zero-emissions vehicles"] (Bogotá: UPME, 2017), http://bdigital.upme.gov.co/handle/001/1160.

3 Law No. 1964, Congress of Colombia, July 11, 2019, https://dapre.presidencia.gov.co/normativa/normativa/LEY%201964%20DEL%2011%20DE%20JULIO%20DE%202019.pdf.

4 The statutory target date is 2035. However, TransMilenio has shifted its commitment forward to 2022; Carlos Bueno and Oscar Delgado, *Buses Cero Emisiones en Bogotá a Partir de 2022 – Liderazgo Político para Liderar la Transición* ["Zero-emissions Buses Starting in 2022: Political Leadership for Leading the Transition] (Washington, DC: ICCT, 2021), https://theicct.org/buses-cero-emisiones-en-bogota-a-partir-de-2022-liderazgo-politico-para-acelerar-la-transicion/.

5 Bogotá, D.C., City Council Resolution No. 790, of 2020, Office of the Mayor of Bogotá, December 13, 2020, https://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i=103745&dt=S.

The mechanism for these changes is the TransMilenio Bus Rapid Transit (BRT) system, managed by TransMilenio S.A. as part of Bogotá's Integrated Mass Transit System (Sistema Integrado de Transporte Público) (SITP). TransMilenio has worked to ensure, among other things, that the vehicles used in the provision of the service incorporate modern technology, with particular attention to reducing emissions and thus the environmental impact of transportation in the region.[6] As of late September 2022, Bogotá's public mass transit fleet included 1,485 electric buses, representing nearly 94% of the national total. These vehicles were incorporated gradually, considering the removal of the diesel buses that had been in service in the city's various operating zones.[7]

In view of these circumstances, the aims of this case study are to understand how Bogotá D.C. achieved these goals and how TransMilenio S.A. obtained the necessary charging infrastructure. Accordingly, this analysis summarizes the state of the charging infrastructure for electric buses in Bogotá D.C., while also presenting some of the lessons learned from the case of the TransMilenio system. It focuses on two main issues, namely, how the private sector came to cover all infrastructure costs and how Colombia's endemic regulatory obstacles were overcome.

6 TransMilenio S.A., https://www.transmilenio.gov.co/.

7 E-Bus Radar, "América Latina," accessed March 13, 2023, https://www.ebusradar.org/.

THE CASE: TECHNICAL ASPECTS OF THE FLEET AND ITS INFRASTRUCTURE

TransMilenio's fleet of more than 9,400 buses includes vehicles whose capacity ranges from 50 to 260 passengers. The various models include 27-meter-long bi-articulated buses for 260 passengers; 18-meter-long articulated buses for 160 passengers; 12-meter-long *padron* (standard) buses for 80 passengers; and 9- to 10-meter-long *busetones* (compact buses) for 50 passengers. Each type of bus has its own charging method, as shown in Table 1. Of the 10 types of buses allowed by Colombian law, TransMilenio S.A. uses only four for mass transit in Bogotá. And only one of the types of buses used by TransMilenio (the battery electric model) is a zero-emission bus. Hydrogen-powered buses are still in the testing phase, through a pilot program. To avoid confusion about low-emission technologies, we are limiting discussion of these technologies to zero-emission electric buses.

Table 1. Types of energy used and approved for use in mass transit buses under Colombian law in 2022

Types of energy	In use
Diesel	✓
Natural gas	✓
Diesel hybrid buses	✓
Parallel hybrid	
Plug-in and/or opportunity charging hybrid	
Battery electric*	✓
Plug-in and/or opportunity charging electric	
Electric with induction charging	
Trolley bus	
Hydrogen	

"✓" indicates the buses were being operated on public roads by TransMilenio in Bogotá, Colombia, as of 2022.

To build the system's infrastructure, TransMilenio S.A. defines the operating parameters, which the Urban Development Institute (*Instituto de Desarrollo Urbano*, IDU) uses as a basis for performing the studies, creating the designs, and executing contracts for construction of infrastructure to implement its operation. The operating parameters of the demand to be met make it possible to determine the specifications of the fleet to be used.

In terms of electrical infrastructure, each type of bus has its own distinct requirements and complexities. Trolley buses, for example, require infrastructure along the entire length of the track. Battery electric buses and hydrogen buses require infrastructure only at their depots, in the same way as traditional diesel buses and buses powered by compressed natural gas. Another option for electric buses is to use fast-charging stations along their route, in a process known as "opportunity charging." For plug-in and/or opportunity-charging hybrid and electric buses (or pantograph charging, with the charger coupled to the bus or to the charging infrastructure located along its route), as well as for electric buses with induction charging, infrastructure must be present at depots, portals, or stations, depending on the configuration and the degree of independence of the buses. When electric bus routes are planned, it must be confirmed that the vehicle is compatible with road conditions and operating requirements. This can be done through studies of the routes and pilot programs.

Table 2. Characteristics of various types of charging for electric buses[8]

Type of charging	Power	Cost (USD)	Charging location
Charging at the depot	120 to 240 kW	$5,000 to $25,000 per unit	Depot sites
Opportunity charging	300 to 500 kW	$120,000 to $150,000 per unit	Pantograph or inductive stations along the route
Dynamic charging	> 600 kW	$260,000 per kilometer of catenary	Continuously along the route

Some of the specifications for the support infrastructure (also known as "preparation sites") include maintenance areas, parking spaces, energy supply, and administrative areas. It is important to differentiate between support infrastructure and electrical charging infrastructure. Support infrastructure (also known in the industry as "charging infrastructure," but not always used that way in this report) also includes administrative and maintenance areas, as well as the other, more general services necessary to provide comprehensive bus-based mass transit services.

As of September 2022, TransMilenio S.A. had 1,485 electric buses in Bogotá D.C.. Nine of the system's 58 depots provide electrical charging. The buses are always charged at the depot site (charging system characteristics are described in Table 3). As part of the project, studies were conducted in other

8 TransMilenio S.A., *"Análisis del sector de tecnologías de cero o bajas emisiones"* ["Analysis of the zero- or low-emissions technology sector"] (Bogotá: TransMilenio S.A., 2020), https://www.transmilenio.gov.co/loader.php?lServicio=Tools2&lTipo=descargas&lFuncion=descargar&idFile=53153.

cities, and some of those cities' good practices were adopted. For example, slow charging is being used, as it is in Cali and Medellín, Colombia and in Santiago, Chile.

The technical data sheet for the charger used with electric buses must indicate compliance with international standards for manufacturing, power, voltage, rated current, and operating frequency, as well as the protection index, insulation level, number of cables (or dispensers), type of connector, length of the cables, charging supply system (AC/DC), and any other relevant characteristics. Some of the most important specifications are cited in Table 3.

Table 3. Characteristics of a TransMilenio 12-meter electric bus in Bogotá[9]

Characteristic	Manufacturers: BYD and Yutong (China)
Power output (MW)	300 kW (two motors, each rated at 150 kW)
Number of chargers and their capacity (kW)	150 kW, two cables simultaneously, with a single charger serving two buses and with each bus receiving 75 kW
Buses: Estimated autonomy range (km)	350 kilometers
Buses: Batteries (type and capacity, in kWh)	LiFePO4 (lithium-iron-phosphate) battery, rated at 350 kWh
Type of connector	GB/T or CCS
Charging time	On average, two hours are required for full charging of most buses with new batteries, and up to four hours are required for a 5 year old battery (at the end of the contract)
"Smart" charging and other information	The battery supplier is responsible for replacing the battery after seven years and for guaranteeing the useful lifetime of the product. The state of health of the battery must be 75% to 80% before being replaced

THE PRIVATE SECTOR

Compared to conventional diesel-powered buses, electric buses require a new business model, as the upfront costs of the buses and their charging infrastructure must be included, along with the total cost of ownership for the useful lifetime of each electric bus, which is less than that of a diesel bus.

A major challenge under these circumstances consists of having, from the start, a suitable design for charging infrastructure, which must be robust enough to support full-scale operation. The design must include, for example, investments in new electricity grids and special permits. For the operation of electric buses, the organizational structure also requires, in addition to a fleet supervisor and financial and administrative director, a

9 TransMilenio S.A., *"Análisis del sector de tecnologías de cero o bajas emisiones"* ["Analysis of the zero- or low-emissions technology sector"] (Bogotá: TransMilenio S.A., 2020), https://www.transmilenio.gov.co/loader.php?lServicio=Tools2&lTipo=descargas&lFuncion=descargar&idFile=5315.

maintenance coordinator for electrical infrastructure. Table 4 shows the various organizational duties and responsibilities required for this type of project.

Table 4. Duties and responsibilities required within the organizational structure of a charging system

Category	Type	Duty or responsibility
Supplier (Supply concessionaire)	Suppliers of the electrical infrastructure	Enable use of the electricity grid
	Suppliers of the infrastructure that supports the operations	Responsible for the depot sites and for the other infrastructure equipment that uses the electricity grid
	Fleet suppliers	Responsible for the buses
Operator (Operating concessionaire)	Operators	Manage the day-to-day operation of the buses and associated infrastructure. The operator does not own the fleet, but has full control over the fleet and its infrastructure, for the successful provision of service.

The private sector finances part of the costs of the infrastructure (e.g., the electrical substation, the electricity grid, and the chargers) in exchange for a monthly fee, either as part of the lease payment or through compensation associated with the depot site. Meanwhile, electricity costs are covered by the operator or by the operating concessionaire, based on its periodic consumption.

In the case of Bogotá D.C., the first stage (2022) involved three main actors: a supplier (who provided and financed the fleet during the contract); a fleet operator; and a third supplier for the depot. However, the arrangement was not economically advantageous for TransMilenio due to high costs and lengthy contract durations.

After completion of the first stage, during which 497 electric buses were introduced in four electrical depot sites, the decision was made to reconfigure the model and extend it into a third stage. (A second stage used internal-combustion buses, which placed it beyond the scope of this study.)

The bidding process in this third stage involved the selection of a supplier, taking into consideration the lessons learned during the first stage and through operational experience. Examples of charging infrastructure from London, England, among others, were also used. In this stage, the decision was made to use a business model that differed from the first and did not require the involvement of a third party. Accordingly, suppliers and operators were merged into a joint provider that played both roles, so that the process would flow better, with fewer actors involved. During this stage, 1,002 electric buses were obtained and five electrical depots were added to the fleet.

In both stages, TransMilenio was required to grant the concession for management of the depot-site infrastructure by selecting the suppliers through direct assignment. In its proposal, the operator is required to supply either the support infrastructure or the operating site for the infrastructure and for maintenance of the fleet. Table 5 shows the two options for the procurement of electric buses.

Table 5. Differences between the various stages of procurement of electric buses in Bogotá

	Stage 1	Stage 3
Type of procurement	Procurement not linked to the provision of support infrastructure	Procurement linked with operations
Description of the actions of the suppliers	Fleet supplier: • Provision of vehicles to the SITP third party: • Provision of the infrastructure, including maintenance of the charging system	Supplier: • Provision of vehicles to the SITP • Provision of the infrastructure, including maintenance of the charging system
Description of the actions of the operators	Operator under a direct contract, with operations and infrastructure contracted jointly for: • Operating the fleet • Maintaining the fleet • Managing, operating, maintaining, and administering the infrastructure	Operator under two concession contracts: • Contract 1: Operating and maintaining the fleet • Contract 2: Managing, operating, maintaining, and administering the infrastructure
Other important points	• Direct contracting with the Condensa company through the bidding process • Operation and procurement through a third party • Due to the difficulty of obtaining bank financing, a lease agreement was necessary (although more expensive over the long term) • Under the contract, the bus supplier must provide the infrastructure	• Cash flow that can be managed by means of a fee arrangement • Lease remuneration (a rental cost within the fee arrangement) • Lesson learned from Stage 1: Do not use lease agreements (instead, work directly with TransMilenio)

REGULATORY FRAMEWORK

The second major question examined by this study is how regulatory obstacles in Colombia were overcome. Because of its regulatory framework, the country poses challenges for infrastructure development.

In any project involving a survey of electric buses, the provider of electrical infrastructure can usually assist with the short-term identification of viable sites and rates for each site. Meanwhile, long-term electrification plans are necessary to ensure that the grid can withstand the load.[10] A transit study is necessary during the initial stages of a project, to determine traffic conditions (in terms of vehicular congestion) before and after the project. Limitations on land use, environmental restrictions, and depot locations are also pertinent, but would be the same for any type of bus, regardless of whether it is electric or powered by an internal-combustion engine. Therefore, the design of an electrical depot must include an assessment of the energy requirements for route-selection purposes, followed by a pilot program before scaling up the project. This approach helps answer questions such as which type of charging should be used (e.g., charging at the depot or opportunity charging) and how many charging stations will be necessary (along with information about the model and the power level of each charger). It is essential to take advantage of the lessons learned by companies such as TransMilenio, which have already been able to answer these questions and demonstrate how to proceed more advantageously.

First, to provide a supply of energy, four stages—planning, design, construction, and implementation—must be completed. The most important requirement of this process (because of its novelty in terms of its use in the transportation field) was compliance with Colombian Technical Standard No. NTC-2050, which is the Colombian electrical code. Table 6 lists the laws and regulations that apply to electric buses.

10 Pamela MacDougall, "4 main takeaways from America's top transit agencies on electrifying buses," *Energy Exchange* (blog), Environmental Defense Fund, July 28, 2022, https://blogs.edf.org/energyexchange/2022/07/28/4-main-takeaways-from-americas-top-transit-agencies-on-electrifying-buses/.

Table 6. Pertinent legislation and regulations for procurement of electric buses in Bogotá

Legislation	Major aspects
Law No. 1819, of 2016	Adoption of structural tax reforms determining the tax on products and services
Law No. 1964, of 2019	Introduction of incentives for owners of electric vehicles; establishment of goals for construction of the charging infrastructure; and authorization for towns and cities to create public-private partnerships in order to encourage such construction
Law No. 2128, of 2021	Encouraging use of fuel gas in Colombia
Law No. 2169, of 2021	Encouraging low-carbon development in Colombia, through establishment of minimum goals for carbon neutrality and climate resilience
Colombian Technical Standards Nos. 4901-1, 4901-2, and 4901-3, of 2009	A series of regulations governing the minimum technical requirements for the safety and comfort of urban mass-transit passenger vehicles: Part 1: Articulated buses Part 2: Test methods Part 3: Conventional buses
Colombian Technical Standard No. 2050, of 1998	The Colombian Electrical Code, which consists of regulations for the protection of persons and property against the risks that may arise due to the use of electricity
Colombian Technical Standard No. 5296, of 2004	Regulations governing the use of pyrotechnic materials that may be used in proximity to the general public
Colombian Technical Standard No. 5701, of 2009	Regulations governing the use of mass transportation vehicles

The concept of "pioneer advantage" is relevant to this study. This advantage consists of the ability to outperform one's competitors as a result of being the first to market a new class of products, such as electric buses. However, due to its lack of experience (because of being first), it is also likely that the initiator of such an effort will encounter a lack of regulatory support and a dearth of infrastructure, as well as financial uncertainties. For example, under Colombia's national policies, electric buses were exempt from value-added tax and import duties; however, operators that purchased such buses were required to complete voluminous paperwork to obtain refunds—an inefficiency that was not discovered until the first operator decided to purchase and test zero-emission buses.[11]

Later operators benefited from an optimized policy that the pioneer operator helped devise. However, in this instance, a perverse incentive (that is, an incentive with undesired consequences) was created, in that certain operators that were less willing to take a risk waited for others to take the initiative in their stead. In our context, this could mean that policies intended to accelerate and encourage the adoption of electric buses have the contrary effect of

11 Law No. 1819, of 2016, Congress of Colombia, December 29, 2016, https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=79140; Yihao Xie and Leticia Pineda, *Module 5: Pilot and Demonstration Projects in the Urban Bus Fleet Technology Transition* (Washington, DC: ICCT, 2022); https://www.youtube.com/watch?v=pDZou2TrQxE.

delaying the operators' efforts. Nevertheless, being a pioneer also has certain advantages, especially in cities, regions, and countries in which pressure is mounting for operators to modernize their fleet to meet stricter emissions standards or even to achieve zero emissions. Early adopters will also discover opportunities to streamline processes; this knowledge could be turned into a business service that subsequently can be sold to other operators.[12]

On the other hand, the impact on the electrical infrastructure (or grid) must be assessed to ensure a sufficient supply for the area in which a charging station is located, as well as nearby businesses and residences. Apart from this impact assessment, there are currently no general limitations on the use of electricity. Operators are guaranteed the availability of energy in their networks as provided by their distributors, and Colombia is well positioned for the generation of hydroelectric power, among other renewable energy sources. At present, the greatest energy-related requirement is for the charging period (of two to three hours) to take place at night; for this purpose a nearby electrical substation must be available to provide the energy.

The lack of specific depot sites designated for use by electric buses causes negative environmental, urban-planning, and mobility effects that impact nearby residents. Reducing these effects in Bogotá will require the creation of land-use plans, which must be implemented through a concerted planning process for the approval of such depot sites.[13] In the past, operators have struggled to obtain permits for depot sites because of their large size, associated costs, and the limited amount of city land available for development. Obtaining permits can also be difficult, because diesel fuel and gas are regulated through tax benefits, while electrical energy has not enjoyed the same advantage.

Electric bus fleets are charged during their maintenance windows, primarily during early morning hours, when consumption and costs are lower. This practice also has a regulatory advantage, because as part of the unregulated market, energy can be bought at auction through its distributor or marketer.

Price is a major obstacle that must be addressed by public policies for the use of electric buses to become feasible. For example, it is advisable to define

12 Yihao Xie, *Soot-free and Zero-emission Urban Bus Fleets Technology Transition Curriculum*, (Washington, DC: ICCT: 2021), https://theicct.org/video-bus-curriculum-sep21/.

13 Law No. 388, of 1997, Congress of Colombia, July 18, 1997, https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=339.

requirements for the minimum degree of autonomy specified in a contract and for reducing daytime charging, especially during peak energy use hours, when buses cannot be charged due to the high price of, and demand for, energy.

Finally, the rise of different charging technologies has been accompanied by an increase in confusion about how to charge the buses. To avoid this confusion, contractual requirements must be imposed on the manufacturers and suppliers of charging stations, to ensure that the equipment that is delivered accurately reflects what was promised.[14] These requirements will protect transit companies such as TransMilenio from stranded assets and will help maximize the long-term viability of the chargers.

14 MacDougall, "4 main takeaways from America's top transit agencies on electrifying buses."

CONCLUSION

This case study described certain good general practices that are recommended for all companies planning to implement charging stations for electric buses. In Bogotá D.C., one of the most important lessons was the need for the private sector to cover certain costs: for example, when the decision is made to cover the infrastructure costs by merging the supply and operating services. Another lesson learned was the importance of working with the public sector to overcome regulatory obstacles, as was done in the case of TransMilenio S.A.. It should be noted that the operating model for any project involving electric buses and their charging infrastructure requires a detailed analysis at the operational level for each situation in each market, and that conclusions should not be drawn without an in-depth analysis of each market.

The city of Bogotá D.C. is already well on its way toward the complete decarbonization of its bus fleet. The path has been laid and lessons have been learned (some that will require repetition and others that should be left in the past, with notes as to why they should not be repeated). Benefiting from the pioneer advantage is not an easy task, and it is important to extrapolate these lessons to other cities and countries. It will also be important to implement good practices that can be replicated in other markets.

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