EletroMobilidade
Transição para a Eletromobilidade
nas Cidades Brasileiras

TECHNICAL REFERENCE MANUAL

FOR ELECTROMOBILITY IN BRAZILIAN CITIES

VOLUME I

TRANSITION TO **ELECTROMOBILITY**
IN BRAZILIAN CITIES PROJECT

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SUMMARY

LIST OF ACRONYMS AND ABBREVIATIONS

ABNT	Brazilian Association of Technical Standards
Aneel	Brazilian Electricity Regulatory Agency
ANTP	National Association of Public Transportation
IDB	Inter-American Development Bank
BNDES	National Bank for Economic and Social Development
BRT	Bus rapid transit
BYD	Build Your Dreams
Capex	Capital expenditure
CMTC	Municipal Public Transport Company
CO_2	Carbon dioxide
Comfrota	Steering Committee for the Fleet Replacement with Cleaner Alternatives Monitoring Program
Cofins	Contribution to the Financing of Social Security
TRM	Technical Reference Manual
DOTS	Transit Oriented Development

EPE Energy Research Office

FGV Fundação Getúlio Vargas

Fundep Research Development Foundation

GdM Mobility Management

GHG Greenhouse gases

GIZ *Gesellschaft für Internationale Zusammenarbeit* [German Agency for International Cooperation]

CNG Compressed natural gas

HVIP California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project

IBGE Brazilian Institute of Geography and Statistics

ICCT The International Council on Clean Transport

ICMS Tax on Circulation of Goods and Services

Idec Brazilian Institute for Consumer Protection

IEMA Institute for Energy and Environment

IoT Internet of things

IPI Tax on Industrial Products

ITDP Institute for Transport and Development Policy

LABMOB Laboratory of Sustainable Mobility

LUL	London Underground Limited
MCTI	Ministry of Science, Technology, Innovation, and Communications
MDR	Ministry of Regional Development
PM	Particulate matter
NO_x	Nitrogen oxides
SPL	Sound pressure level
NTU	Brazilian National Association of Transport Operators
SDGs	Sustainable Development Goals
WHO	World Health Organization
UN	United Nations
Opex	Operational expenditure
PIS	Social Integration Program
PPP	Public-private partnership
PNME	National Platform for Electric Mobility
Proconve	Car exhaust testing program
Rise	Network of Innovation in the Electric Sector
Senai	National Service for Industrial Training
TCO	Total cost of ownership

Teemp	Transport Emissions Evaluation Models for Projects
Tumi	Transformative Urban Mobility Initiative
UFRJ	Federal University of Rio de Janeiro
Unicamp	State University of Campinas
LRV	Light rail vehicle
NPV	Net present value
WRI	World Resources Institute

EXECUTIVE SUMMARY

The Technical Reference Manual (TRM) for Electromobility in Brazilian Cities (Volume I) seeks to contribute with reliable and systematized technical content on battery electric bus projects and how to properly plan, implement, operate, and manage them. Many cities still face difficulties in this area or do not know how to begin the transition to fleets with cleaner and zero-emission technologies. This manual seeks to make this process easier by proposing short, medium, and long-term tools and recommendations for an effective and large-scale operation.

Despite the challenges of introducing this technology, the successful transition to battery-powered electric buses is already a reality in different cities in Brazil and the world. In Latin America, the electric fleet grew 200% in five years. By 2040, battery-powered electric buses could exceed 1.3 million vehicles. In addition, it could account for more than 50% of the planet's total global bus fleet.

For over half a century, fossil fuel-powered engines in urban fleets have been the main reason for increased air pollution and related diseases. In addition to contributing to global warming, combustion-powered vehicles are also the main responsible for the emission of local polluting gases, which can cause cardiovascular and respiratory diseases, one of the main causes of death in the country.

With the pandemic, the worsening of environmental and sanitary threats added to the fall in demand for passengers on public transport, which subjected the public transport systems in Brazil to extremely critical financial conjunctures. As a result, city leaders are being challenged to radically change the operation of their transport systems to make them financially and environmentally sustainable.

However, many municipalities still face challenges in effectively adhering to electromobility because of operational, financial, and legal barriers. To begin this transition, this manual highlights efficient ways to overcome these obstacles, especially financial ones. The initial investment is high and can vary from US$260,000 to US$475,000 in Latin America; on the other hand, the costs of operating and maintaining electric fleets (including batteries and charging infrastructure) have the potential to be up to 70% lower than conventional diesel buses [1].

Many cities are still analyzing the most appropriate model for implementing an electromobility system that provides scalability. A business model designed to mitigate investment risks for all parties is one of the main recommendations to accelerate the change. The recommendations proposed in this manual aim to support the design of these models and adapt them to the context of each city based on the analysis of lessons learned so far. The experience of pioneer cities in Latin America, such as Bogotá (Colombia) and Santiago (Chile), demonstrates that the contractual separation for the implementation and operation of electric buses between public and private entities is potentially advantageous given the uncertainties surrounding the initial stage of a technology that is still little disseminated [2]. Chapter 3 presents such experiences and the advantages and limitations of each business model for introducing electric fleets.

Traditionally, contracting models tend to give private companies the system's operation, leaving the government responsible for supervision and management. On the one hand, this releases cities from the costs of public transport; on the other hand, it holds only one of the parties involved accountable for innovations and quality of service. An alternative to this model, addressed in this technical manual, would be the sharing of activities and risks to provide further cooperation and responsiveness to the economic, social, and environmental demands of an electric bus project, which can improve the quality of service without burdening or overloading only one of the parties.

The stages of implementation of corridors or lines using electric buses should provide for the detailing of the regulatory model; the definition of fleet funding; the definition of the route to be electrified; the definition of the type and location of the charging infrastructures; monitoring and management of the operation; maintenance; and support activities.

This manual also demonstrates that elaborating the regulation model of the transport service to be offered (either by concession contract, permission, or authorization) requires profound changes to enable the transition and ensure the implementation at scale in the cities. In addition to changing the type of vehicle that circulates on the streets, the transition to fleets with cleaner technologies and zero emissions requires planning in several stages.

In short, implementing electric buses implies planning a new public transport system. However, despite the challenges, it is an opportunity to rethink and improve urban mobility as a whole (not just passenger transport service).

In addition to technological innovation, the cities that implement electromobility projects should be able to provide means for a more equitable and comprehensive economic and social development, mainly benefiting the population groups that depend most on public transport: low-income population, black people, women, people with disabilities, the elderly, and children. In this sense, prioritizing the electrification of the most demanded routes by this public is equivalent to investing in expanding access to opportunities with relevant social and economic returns.

This manual provides guidelines for planning decarbonization-oriented public transport electromobility to ensure that the project generates effective results. Lessons learned and shared by pioneer cities in Latin America, such as Santiago and Bogotá, demonstrate that introducing electromobility in Brazilian cities is possible. In addition, the manual indicates the most recommended and viable paths to a successful transition to zero-emission fleets.

INTRODUCTION

Electromobility is one of the most powerful solutions to drive sustainable and inclusive urban development. Yet, for more than half a century, the primacy of fossil fuel-powered transport has helped shape and expand polluted, hard-to-reach cities.

Now, local governments have the opportunity to write a new chapter in the history of their cities. The Technical Reference Manual (TRM) for Electromobility in Brazilian Cities (Volume I) provides subsidies to support Brazilian municipalities in the transition phase. Despite the numerous social, economic, and environmental benefits already tracked and proven [3], battery electric buses are still a technology whose adoption faces several challenges. In this sense, the manual has the following purposes:

- Identify and present guidelines and procedures for the transition, considering technical characteristics, benefits, opportunities, and barriers to electrification;

- Present guiding and procedural methods to drive a transition in Brazilian cities, considering strategic, institutional, contractual, operational, and financial issues, in addition to the main restrictions for the implementation of electromobility;

- Indicate instruments and recommendations for the effective implementation of electric buses with procedures for assessing and monitoring the impacts of environmental and socioeconomic externalities.

In addition to the executive summary and a section dedicated to final considerations, the manual's content is divided into six thematic chapters:

Chapter 1. Bus electromobility and the national context: introduces basic information about electric buses and an overview of progress in Brazilian cities. It then presents the main barriers to adopting technology and the opportunities based on examples of what some cities are doing (or have already done) to enable fleet replacement.

Chapter 2. Social, environmental, and economic impacts: explores the externalities cities would potentially have from adopting electric buses. The impacts are analyzed in depth and across environmental, social, and economic terms.

Chapter 3. Electromobility planning: offers the main recommendations and guidelines for implementing electric bus systems, reconciling the financial and technical aspects of electromobility with the socioeconomic specificities of the municipality.

Chapter 4. Business models for electromobility: highlights the main options available for agreements between the parties, indicating criteria for cities to choose the most advantageous and safe ones to implement electric fleets at scale.

Chapter 5. Means of implementation of projects: presents political and regulatory instruments, governance mechanisms for the system's operation, and guidelines for effective operationalization.

Chapter 6. Monitoring and evaluation: indicates the procedures for the elaboration and/or adoption of instruments to monitor and evaluate the efficiency of electric buses.

1.

ELECTRIC BUSES IN THE NATIONAL CONTEXT

In the quest for sustainability, electromobility is a pragmatic and efficient solution that contributes to mitigating greenhouse gas emissions (GHGs) causing climate change and improving air quality for the population.

Different cities in Brazil and worldwide have begun to bet on electrification as an alternative technology to conventional mobility based on burning fossil fuels [4]. In Latin America, the electric bus fleet increased from 731 to 2,482 vehicles between 2017 and 2021. Currently, Brazil has 350 electric buses circulating in nine cities in the South, Southeast, and Midwest regions [5], and an increasing number of cities are conducting tests to add electric vehicles permanently to their fleet.

This chapter presents an overview of the transition to electric buses by 2021. First, the experiences already implemented and/or ongoing are examined, focusing on the trajectory of the most advanced cities in electrification in Brazil and the world, as well as the main institutional, financial, social, and regulatory barriers and opportunities that individualize this experience.

From these aspects, the chapter describes how each of these cities enabled the beginning of the transition, highlighting the influences (national or international), good practices, and policies adopted. Then, the institutional arrangement around the transition process to electromobility is characterized by distinguishing the participation of public and private stakeholders at the municipal, state, and national levels. Finally, it presents a balance of the main results evidenced so far to highlight the best experiences, the challenges faced, and their achievements.

1.1 WHY MAKE THE TRANSITION TO ELECTROMOBILITY?

Cities must take action to meet their commitments to reduce pollutant emissions. Between 70% and 80% of greenhouse gas emissions and other air pollutants resulting from the burning of fossil fuels are generated in large urban centers, especially in the transport sector. Cities account for less than 2% of the continents' area but serve as a residence for more than 50% of the entire planet's population [6].

In 2016, the Paris Agreement was signed, whose main objective was to ensure that the increase in global average temperature did not exceed 2°C above pre-industrial levels — preferably, the limit should be 1.5 °C. Among the 195 signatory countries, Brazil has set the goal of cutting GHG emissions by 37% by 2025, with an indication of a 43% reduction by 2030 —compared to 2005 levels. **Electromobility is a key factor in achieving this goal, and cities play a crucial role as change agents.**

The UN New Urban Agenda guidelines, enacted in 2015, provide for 17 Sustainable Development Goals (SDGs) with goals to be met by cities by 2030. In addition, SDGs 7 (Clean and Affordable Energy) and 11 (Sustainable Cities and Communities) highlight the urgency of the electrification of public transport.

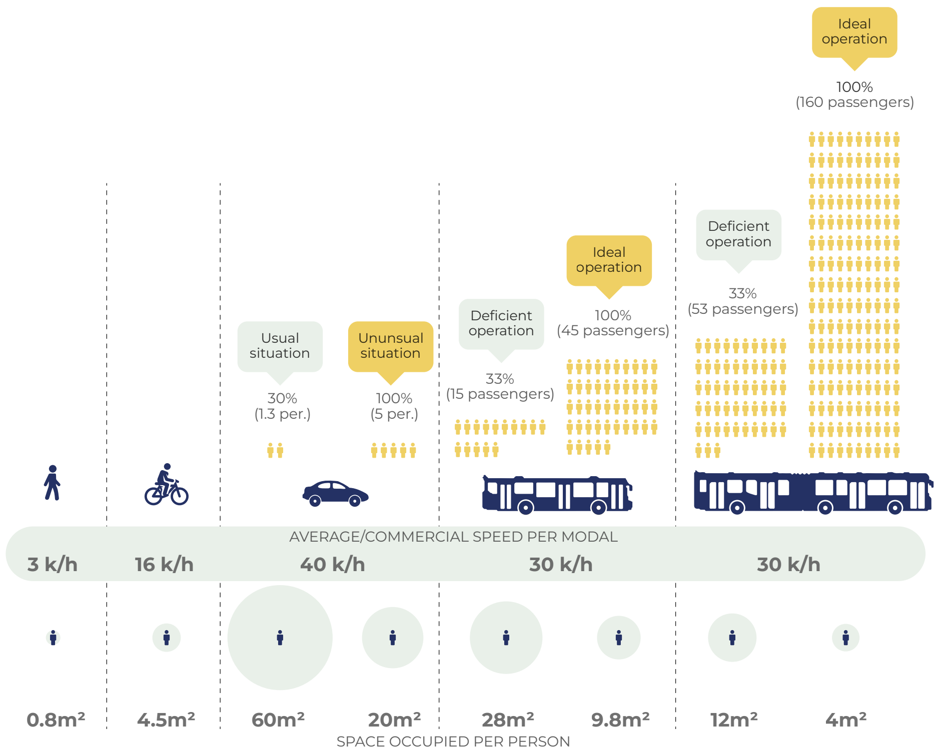
In the urban transport sector, the transition can begin with buses, which account for 86% of travel in Brazil [7]. In addition to being one of the largest greenhouse gas emitters alongside individual motorized vehicles, conventional diesel buses emit local polluting gases that are highly harmful to the population´s health [8].

In 2021, the bus fleet in São Paulo issued more than one hundred tons of particulate matter. The impact of exposure to polluted air corresponds to smoking five cigarettes per hour, according to results of research led by Professor Paulo Saldiva from the Medical School of the University of São Paulo (USP), which assessed the lungs of 413 autopsied corpses in the state capital [9]. These emissions degrade the quality of life of several neighborhoods, forming islands of heat and smog that generate immense thermal discomfort and potentiate their effects by hindering the evaporation of these gases, keeping them concentrated and dense at the height of the nostril.

Introducing electric fleets allows cities to make their bus services more comfortable, safe, and reliable, especially for people who rely most on them to move around the territory —such as low-income people, people with reduced mobility, women, and black people. These benefits are further explored in Chapter 2.

At the same time, electromobility needs to be prioritized in shared transport modes, which are efficient in the use of road space and the number of people transported. Electric cars, for example, use less polluting vehicle technology than combustion-powered cars; but do not contribute to a fairer distribution of public spaces on the streets and avenues. Figure 1 illustrates the efficiency of using space in transport according to the type of vehicle. It is observed that in a usual situation of trips in individual motorized transport with a person driving, the space occupied is 60m^2, while in an exemplary operation of public transport of 45 passengers per bus, the space occupied per person falls to 9.8m^2.

Figure 1 – Efficiency of the use of space in transport by type of vehicle



Source: Own elaboration, based on ITDP (2015) [10].

It is estimated that it takes about one hundred electric cars to provide the same benefits a single 18-meter (articulated) electric bus offers. For every 1,000 electric buses circulating in the road space, 500 barrels of diesel are saved. In contrast, 1,000 battery electric cars prevent the use of only 15 barrels of oil [11].

The transition to electromobility is also a way to eliminate several stigmas attributed over time to public transport by bus, such as thermal discomfort and noise pollution. In this sense, it is an opportunity to stimulate cities to promote a structural transformation in the planning of their transport systems, making the road space more equitable, safe, and integrated for pedestrians and cyclists.

Figure 2 – Shenzhen City (China) pioneered the transition to a fully electric bus fleet and today reaps several benefits

Credit: ITDP China (2020).

Shenzhen city is today the leading reference in electromobility in the world. The electrification of its fleet was supported by a national policy of tax incentives, favorable regulation, and robust investment in technology, which made the city the locus of innovation and prosperity for public transport, with many positive externalities. In 2009, Shenzhen pioneered worldwide testing of electric buses. Less than a decade later, in 2017, 100% of its fleet had already been electrified (about 16,400 vehicles). **The complete transition reduced dependence on fossil fuels by 95% and consequently improved air quality for its 12 million inhabitants** [12].

- About 1.3 million tons of CO2 ceased to be emitted annually with the total conversion of the fleet.
- Other polluting gases, such as nitrogen oxides and particulate matter, were reduced by 431.6 tons.
- Based on the 2016 operating mileage, electric buses consumed 72.9% less energy than diesel buses.

1.2 ELECTROMOBILITY IN THE PUBLIC TRANSPORT SYSTEM BY BUS

Electromobility refers to vehicle motorization technologies that adopt electric energy as a driving force. In addition to electric buses, the term covers a range of other vehicles that have already been developed by the industry, such as electric bicycles, electric scooters, electric cars, electric motorcycles, and even electric trucks. Several terms are also commonly used to deal with electromobility: electric mobility, e-mobility, and transport electrification, among others. The electromobility in public transport includes hybrid and fully electric buses, which can be trolleybuses or battery-powered (Figure 3).

Figure 3 – Trolleybus in operation in the Metropolitan Region of São Paulo (left) and battery electric buses in Maringá, in Paraná (right)

Credits: Renato Lobo (2018); Rafael Calabria (Idec, 2019).

The trolleybus is a vehicle that has, at its top, cables connected to an overhead electrical network covering the entire itinerary. This technology has been consolidated in Brazil since the 1940s. Cities such as Rio de Janeiro, Niterói, Araraquara, Recife, Belo Horizonte, Ribeirão Preto, and Porto Alegre have already used this technology in their public transport systems by bus throughout the 20th century; until 2021, the trolleybuses were present only in the Metropolitan Region of São Paulo [13]. An advantage of the trolleybus is that they have guaranteed autonomy throughout the route. However, they lack the flexibility to change the route due to the rigidity of the infrastructure.

Autonomy is the capacity that a battery vehicle travels considering a full charge. Generally, the battery electric buses adopted in Brazil and Latin America have average autonomy to travel approximately 250 km uninterrupted at each complete charge, usually made in the garage.

Battery-powered buses adopt a more modern technology than the trolleybus. They have greater flexibility to move around the city with more independence, which increases the capillarity and efficiency of the public transport system. **The battery embedded in the vehicle is usually composed of lithium ions, a chemical element with high energy efficiency.** This extends the ability to keep vehicles in circulation without requiring sequential charges. In addition, they also have a **regenerative braking system**, whose energy used in the engine deceleration process is transferred to the battery by charging, broadening the efficiency and autonomy of travel.

Why do battery electric buses have greater strategic potential?

Battery electric buses have enormous potential to improve public transport systems sustainably and equitably. They are becoming popular and gaining scale thanks to several enhancements:

- Ability to travel potentially longer distances as they can be improved, in addition to battery technology, driver training to drive the vehicles, charging methods, and good maintenance practices;

- As the industry achieves economies of scale, acquisition costs can potentially decrease;
- Evidence-based decision-making with increased data and good practices shared between cities;
- A better understanding of how to use technologies as more cities conduct pilot projects in diverse geographic and economic contexts; and
- Funding opportunities can be made possible by donations and innovative funding programs. The possibilities in this sector are diverse and still poorly developed, considering the needs of the municipalities.

Batteries can be charged using three types of infrastructure.

The traditional plug-in charge is the most common method – and usually more accessible to cities. In addition, it is what makes less intensive use of electricity. A cable coming out from the vehicle connects to a switch installed in a totem, which can vary in size depending on the manufacturer and electrical power. The charging time is variable, but usually takes five to eight hours to reach full charge. These infrastructures can be allocated in specific garages and/or points, commonly at the beginning or end of routes. Generally, a plug-in infrastructure can power one or two vehicles simultaneously. The average power ranges from 25-150 kW. Although the infrastructure is more financially accessible, the battery pack is more expensive than other charging methods, such as pantograph and wireless. Batteries are also bigger and heavier [14].

Figure 4 – Traditional plug-in charging infrastructure in Washington, D.C., United States

Source: BeyondDC, Flickr (apud ITDP, 2021).

This charging method is also called overnight charging, as many batteries are charged at dawn to start operation the next day with the full charge or close to 100%. Overnight charging can also be adopted as an alternative to reduce costs since the value of electricity tends to be lower during the nighttime. However, this is not a rule, as overnight charging is an operational decision. In addition, decisions about the periodicity and time of charging also usually consider variations in the electricity rate throughout the day or when the electrical grid is less overloaded.

Establishing an efficient articulation between the stakeholders involved in the processes that make up the implementation of this type of infrastructure is a fundamental aspect to be worked on by municipalities that opt for this type of technology. The articulation of the new institutional arrangements should include suppliers and concessionaires of distribution and commercialization of electricity to understand and/or adapt the most effective way of operating the charger chosen to power the system. In China, the world's largest electric bus and charger market in 2021, the traditional plug-in is the most popular method [15].

Table 1 – Battery electric bus charging infrastructures

	Traditional plug-in	Charging by pantograph	Inductive Charging
How to transfer electricity?	Also known as night loading. Most common and accessible method.	Contact between a pantograph and the rods installed on the vehicle's roof.	Inductive or by opportunity charging uses an electromagnetic field to transfer electricity.
Charging time	Slow: from 5 to 8 hours to reach full load.	Fast: 5 to 20 minutes.	Fast and dynamic: from 20 minutes to 1 hour to reach full charge.
Where is it located?	At the end/start of routes or in garages.	At the end/beginning of the routes; in garages or stations; and charge along the route (in the case of trolleybuses).	At the end/start of routes, along routes, or in garages.

Source: Own elaboration.

Another charging infrastructure is through a pantograph, following a logic similar to the powering of the trolleybus. For battery electric buses, the pantograph is a punctual infrastructure, which is also usually located in garages or at points along the routes, such as the infrastructure made by vehicles.

Pantograph charging requires the bus to stop under or near a charging device that connects the battery pack to the electricity supply through a rod. The top or side charging mode depends on where the battery pack is located in the vehicle structure. As a rule, battery electric buses charged by pantograph have batteries at the top. These batteries are smaller than those used exclusively for plug-in charging, which makes vehicles lighter and more spacious. The charger's power ranges from 50-450 kW [16].

Figure 5 – Buses being charged via a pantograph in Warsaw, Poland

Source: Wistula, Wikimedia Commons (apud ITDP, 2021).

With the pantograph, the charging is done in a few minutes and allows buses to be operated with a higher turnover — that is, the need for vehicles to be out of service is reduced due to charging. This type of infrastructure has greater cost-benefit advantages for scale electromobility projects in which buses travel many kilometers per day.

On the other hand, although the battery pack is cheaper than those used in plug-in charging, pantograph infrastructure is more expensive for acquisition and leasing [17]. Quick charging can also threaten battery life and autonomy. Moreover, it requires a greater electrical grid capacity to power vehicles with agility, especially when the rate is eventually higher.

Pantograph use is more common in cities with electric fleets in Europe and North America but is also beginning to become popular in China [18].

Finally, there is inductive charging — also called opportunity charging or wireless. Inductive charging uses an underground electromagnetic field to transfer electrical energy to vehicles. Inductive charging tends to have higher costs and longer deployment time, as the infrastructure partially covers sections of the route operated by the vehicles. The power ranges from 50-200 kW.

Figure 6 – Electric buses in Washington state approach an inductive charging infrastructure embedded in the ground

Source: The Philadelphia Inquirer (2021).

The technology has been successfully evaluated and adopted in some European cities, such as Madrid (Spain), Berlin and Mannheim (Germany), London (United Kingdom), and Geneva (Switzerland), among others. In addition, in cities in South Korea – such as Seoul, Gumi, and Daejeon – and the United States – such as Long Beach (California), Wenatchee (Washington), and the bus line connecting downtown Kansas City to the airport (Kansas), to name a few [19].

1.3 THE SUSTAINABILITY OF ELECTROMOBILITY

Investing in electromobility is urgent and allows, at once, to respond to urban sustainability challenges, health, economy, and accessibility.

The pandemic and quarantine measures have also intensified other challenges. The significant decrease in transport users has accentuated the financial imbalance of the systems, many of which rely on tariff revenues to sustain themselves. The average reduction was 80% in demand and 25% in the services offered [20]. In Rio de Janeiro, several operators filed for judicial recovery between 2020 and 2021, which generated unemployment in the sector and impaired the supply and coverage of bus services. The impact was greater for workers from the "essential categories," who could not opt for remote work or voluntary isolation [21].

The operation of electric buses differs substantially from the operation of diesel buses, which requires, at a minimum, that cities invest in training personnel to manage, operate, and maintain corresponding vehicles and infrastructure. The potential of electric buses to boost an innovative and prosperous economic complex, with new jobs related to research and innovation activities, is high. In addition, cities can offer opportunities for retraining and requalification for workers who may be affected by the crisis to re-enter the labor market in the low-carbon transport sector.

By 2030, at least 15 million jobs are expected to be generated by the decarbonization of the economy throughout Latin America. An effective transition helps restore ecosystems and stimulates the production of clean electricity from chain technological innovations. As a result, the number of direct and indirect jobs on the continent could reach 22.5 million [22]. In Brazil, it is estimated that 7.1 million jobs could be created in a low-carbon scenario [23].

In addition, cities generate symbolic benefits when they invest in electromobility. The addition of electric buses can potentially reposition the image of these cities, making them world references in the decarbonization of transport.

Figure 7 – Electric vehicles operating in Santiago de Chile represent approximately 10% of the bus fleet from metropolitan system RED

Credit: MTT Chile (2020).

Chile has the third largest fleet of electric buses on the planet (819), second only to China and Colombia. By October 2021, Santiago (the capital) already had a total of 776 battery electric buses in circulation, in addition to having bid another 991 electric buses to include in its fleet, which will further expand the operation of zero-emission vehicles from 2022. Electric vehicles account for 10% of the total bus fleet. Efforts for electrification benefited from the 2017 National Electromobility Strategy, which established guidelines on a national scale. The law determined that 40% of private and 100% of public transport vehicles will be electric by 2050.

Gains

- The transition to a fully electric fleet could prevent around 1,379 premature deaths by 2030, according to data released by the United Nations Environment Program (2019). At the national level, improving air quality is expected to generate annual benefits of US$8 billion for the health sector, according to Chile's Ministry of the Environment.

- The Chilean government estimates that the operation and maintenance of the new fleet are 70% and 37% more economical than those of diesel-powered buses [24], respectively.

- The rate of passengers who evaded the system and did not pay tariffs fell from 25.8% in 2018 to 3% in 2019, demonstrating that investing in the quality of service positively affects the reliability relationship between operators and users.

- A survey of users revealed that the most praised points of the operation were the perception of lower environmental pollution (83%), air conditioning (72%), the smoothness of the trip (67%), lower noise level (59%) and the comfort of the seats (42%). At least 95% said in an interview that electric buses improved the quality of their commuting.

- Considering the forecast that 25% of buses will be electric by 2030, it is estimated that the number of people affected by respiratory diseases will fall from 40,613 in 2019 to 2,175 in 2030, thanks to improved air quality. Therefore, the expectation is that mortality levels will be zeroed until then, maintaining only the cases of professional leaves/absences and lost school days related to this type of disease [25].

- A tariff reduction agreement with the electric power supplier allowed to optimize the costs of charging the batteries.

1.4 NATIONAL PANORAMA

In the middle of the last decade, many Brazilian cities began the transition to electromobility. Although some are still in the planning phase, others have already implemented and have electric buses circulating permanently [26] .

The Declaration of Green and Healthy Streets guidelines have guided many of the electromobility programs planned and implemented in the country. An example of this is São Paulo, which, in 2018, implemented a regulatory instrument for electromobility aligned with the guidelines of the declaration (see Climate Law, no. 16,802, of January 17, 2018, in Chapter 5). As a result, by June 2022, Brazil already had 351 electric buses in operation —and the number would increase if the electric vehicles used in testing were considered. In Latin America, Brazil is the fourth country with the highest number of electric buses, behind Colombia (1,165), Chile (819 buses), and Mexico (556) [27].

Electric buses already circulate in Brasília (Federal District), Bauru (SP), Campinas (SP), Maringá (PR), São Paulo (SP), Metropolitan Region of São Paulo (SP), Baixada Santista (SP), and Salvador (BA). Most vehicles in circulation consist of trolleybus (302), followed by 48 battery-powered buses. Table 2 presents the number of electric buses, the respective vehicle technologies, and manufacturers per municipality.

Table 2 – Brazilian municipalities with permanent electric buses in the fleet, types of vehicles, and manufacturers

City	Total of vehicles	Type of vehicles				Manufacturers		
		Trolleybus	Midi battery	Conventional battery	Articulated battery	BYD	Eletra	Others
Brasília (DF)	6	-	-	6	-	6	-	-
Bauru (SP)	2	-	-	2	-	2	-	-
Campinas (SP)	15	-	-	15	-	15	-	-
Maringá (PR)	3	-	1	2	-	3	-	-
São Paulo (SP)	219	201	-	18	-	18	201	-
Região Metropolitana de São Paulo (SP)	96	95	-	-	1	73	-	23
Santos (SP)	7	6	1	-	-	1	-	6
Volta Redonda (RJ)	3	-	-	3	-	3	-	-
Brazil	350	302	2	45	1	120	201	29

Source: E-Bus Radar Platform (June 2022).

In Brazil, several cities have conducted tests with electric buses, such as São Paulo, Campinas, São José dos Campos, Curitiba, Rio de Janeiro, Niterói, Salvador, and Brasília. However, despite the importance of assessing the technology in pilot projects, the size and quantity of vehicles in operation in 2021 are not always enough to understand all the benefits electric buses can offer to the population. For this reason, the tests must rely on monitoring the operation and a greater number of vehicles per fleet, in addition to a clear transition strategy.

However, few Brazilian cities have advanced in elaborating plans that deal with the transition to cleaner fleets at scale, except for São Paulo state capital. Since the adoption of the Climate Law (No. 16,802, of January 17, 2018), the concession process for the operation of buses in the city of São Paulo provides for several goals to enable a gradual reduction of emissions of carbon dioxide (CO_2), particulate matter (PM), and nitrogen oxides (NO_x) over the years, with a focus on elimination by 2038.

Table 3 – Brazilian municipalities with permanent electric buses in the fleet, types of vehicles, and manufacturers.

Country	Initial cost of diesel buses (in US dollars)	Initial cost of BEB (in US dollars)	Approximate percentage variation of electric vehicles
China	$ 60,000–$90,000	$ 140,000–$350,000	~ 250%
Europe	$244,000–$420,500	$575,000–$807,000	~ 110%
India	$30,000–$80,000	$105,000–$250,000	~ 220%
Latin America	$200,000–$225,000	$260,000–$475,000	~ 75%
North America	$300,000–$510,000	$550,000–$1,200,000	~ 115%
Global average	~ $210,000	~ $480,000	~ 155%

Source: ITDP. From Santiago to Shenzhen (2022).

The high initial cost of electric buses, ranging from US$260,000 to US$475,000 in Latin America, can also hinder progress in drawing up plans and targets. As a result, many cities do not feel able to raise the necessary resources for the initial investment of an electric fleet at scale. On the other hand, systems with fewer users and less territorial coverage can start with a smaller fleet to realize the positive impacts, and, usually, the articulation between the city and stakeholders tends to be less complex, facilitating decision-making. This is the case reported by the Urban Mobility Department of São José dos Campos [28].

1.5 BARRIERS AND OPPORTUNITIES

Pioneer cities that started the implementation of bus electromobility faced some obstacles during the transition process. If, on the one hand, the existence of financial, legal, technological, and political barriers makes the transition more challenging, on the other hand, it also offers valuable opportunities for cities. This subchapter presents cities' main barriers and opportunities to plan their transition projects with more caution and resolution.

1.5.1 Barriers

The initial high investment in electric buses, ranging from US$260,000 to US$475,000 in Latin America, and the infrastructure associated with them may discourage many cities from planning electromobility projects. Even if the total cost of ownership (TCO) of electric buses decreases over time compared to diesel vehicles [29], the lowest price criterion still guides many administrative processes and credit lines that legally enable the acquisition and leasing of these technologies. Long-term contracts without clauses providing mandatory incorporation of new technologies, targets for reducing pollutant emissions, and quality parameters guided by zero emission criteria also reduce the competitiveness of electric vehicles and impose difficulties on fleet scalability. Although many pilot projects get off the drawing board, they do not evolve proportionally to the demand and/or goals stipulated by the city, given the robustness of the investment. São Paulo, for example, is the Brazilian municipality that leads the ranking with the largest number of electric buses in the country; however, these vehicles still accounted for only 1.5% of the total fleet in 2021 [30].

The TCO includes the lifetime cost of purchasing (capital costs) and maintenance (operating and maintenance costs) of a bus and the costs of installing and maintaining the charging infrastructure.

Electric buses do not come in isolated. Planning to incorporate these vehicles into the fleet means funding and incorporating additional infrastructure that enables their circulation, which also imposes a standardization challenge. An example is the charging infrastructures: their operation requires as careful planning as the vehicles themselves. Cities need large, airy garages to install these infrastructures (especially plug-in-type ones, which require the most space). These garages or charging stations also need to be well-located to expand the circulation of electric buses in various parts of the city and ensure that the infrastructure receives enough electricity to power the vehicles. Because of the new form of planning for the operation of electric fleets, cities may consider them less flexible than diesel fleets. For example, electric buses require adaptation of itineraries and frequency in case of longer routes or lines that operate 24 hours a day.

Electric buses are a relatively emerging technology, and because of this, the availability of qualified professionals to assume positions specialized in electromobility projects is scarce. This is a challenge that affects not only the positions linked to the operation of vehicles — the impacts are felt mainly in management. In the case of electric buses, the shortage of specialists can make it challenging to prepare tenders for hiring and specifying vehicles suitable for each city. Furthermore, battery electric buses have varied performance depending on thermal conditions, profile, and extension of routes and topography, among other factors.

This barrier also applies to professionals' availability to work with the maintenance of vehicles and their respective components. As mentioned earlier, the lack of standardization of vehicles and infrastructure brings learning challenges and price variations. Of course, manufacturers and suppliers can offer technical support to professionals who manage these assets, but this is a palliative solution with no standardization in the regulations and business model adopted by the city.

Electric buses face supplier shortages and resale difficulties. Many cities and operators reduce the maintenance costs of their diesel buses through fleet renewal. To do so, they use a parallel market that allows them to pass on vehicles to smaller cities when they reach a certain age [31]. Large bus operators in major Brazilian cities generally reduce maintenance costs by reselling them to smaller cities. However, the resale of old and polluting buses should not be considered positive in the current model considering the renovation efforts for a decarbonized fleet [32].

Although the vehicular technology used in electric vehicles is free of local emissions to move around, the production chain can be intensive in carbon emissions – especially in battery production and energy sources used for electricity generation. In other words, with no careful and comprehensive planning, pollution that ceases to be emitted on the streets is transferred to power plants or mining and processing raw materials (such as lithium, nickel, and cobalt) to produce batteries. Besides being an environmental challenge, it has also proved to be a geopolitical issue involving extractive territorial disputes, child and slave labor complaints, and threats to the continuance of indigenous peoples [33].

In this sense, Life Cycle Assessment or Analysis (LCA) is a technique that studies environmental aspects and potential impacts (positive and negative) throughout the life of a product or service, from raw material extraction to the final destination. The LCA methodology can be applied for several purposes, including product development and improvement, definition of strategic planning and public policies, sustainability indicators, management of environmental impacts of products and services, and environmentally responsible marketing. In the Brazilian case, LCA is governed by ISO 14040 [34] standards, which determine the structure, principles, requirements, and guidelines that should be included in studies of this type.

In addition, the National Solid Waste Policy (PNRS) determines the principle of shared responsibility for the life cycle of products and the obligation of reverse logistics for the correct management and disposal of solid waste. The Ministry of Environment (MMA) defines reverse logistics as an instrument of economic and social development characterized by a set of actions, procedures, and means aimed at enabling the collection and refund of solid waste [35] to the business sector, for reuse, in its cycle or other productive cycles, or other environmentally appropriate final destination. For some products, due to the degree and extent of the impact of their waste on health and the environment, a specific reverse logistics system (SINIR) should be implemented, such as batteries and/or batteries, electronic components, tires, metal parts, aluminum and plastic used for the construction of electric and/or hybrid vehicles.

The current uncertainty about the end of the batteries' useful life represents a challenge in adopting electric buses. In addition, improper disposal increases overall emissions throughout life, which can be avoided. While companies offering PEV (voluntary delivery points) develop recycling, upgrade, and reuse programs, there is much work left for BEB batteries. Research should focus on understanding how BEB batteries can be reused or recycled, such as using decentralized energy storage or recycling materials for developing new batteries.

The recycling methods of batteries used in BEBs in Brazil are still under development, and are currently adopting the following solutions [36]:

- Battery use in a second-life cycle, such as in solar or wind energy storage, with 96% efficiency. BYD in Brazil is already selling solar panels and closing sales packages for this purpose;

- After the second life cycle (30 years), batteries must be subjected to recycling, in which lithium-ion components are used, and other chemical components to produce new units.

Electric buses can demand atypical electricity charges. This is a particularly complex barrier, but many cities have been dedicated to investing in intelligent power transmission and distribution networks (known as smart grids) to enable the correct functioning of the technology, seeking to avoid risks of “blackouts” in periods with adverse weather conditions. Even so, many operators are still apprehensive about possible electricity cost variations, as seen in the box containing Figure 8.

1.5.2 Opportunities

Recent experience with the Covid-19 pandemic has tested the efficiency and financial viability of various public transport systems in Brazil and worldwide. Improving air quality and reducing emissions have come to be seen as a global public issue. Many cities now need to reformulate bus service concession contracts to adapt them to the new demand, encouraged by society to provide for technological changes that respond to health challenges and climate emergencies.

The revision of contracts is crucial to enable electromobility because they determine technical and operational questions about how the fleet will be made available and how the service will be provided. In this sense, reviewing the conditions of compensation and penalties if the obligations are not fulfilled may have a catalyzing function of technological transition.

Some incentives for transition have been tested by some cities, such as the application of fines for non-compliance with fleet renewal that add environmental quality to the system and the adoption of compensation criteria to operators that meet quantifiable environmental targets.

A reduced contractual period is also recommended to ensure operators can promote more robust changes in the short and medium term. As a rule, the contracting models in force in the country attribute to private companies the system's provision, operation, and maintenance, leaving it to the government to be responsible for its supervision and management. Separating contracts by role (fleet provision, operation, and maintenance) is an alternative to amortizing and dividing high investment costs between different parties.

While the entry of new stakeholders can increase the level of complexity in decision-making processes related to the management, operation, and maintenance of the fleet, it allows, on the other hand, for cities to dilute the expenses with initial technical training because the parties involved would be responsible for the roles in which they already have expertise. The disposal of batteries at the end of their useful life, for example, may be under the responsibility of one of the parties (usually the supplier) based on a lease arrangement of components. The risk-sharing business model can also support a governance model that responds to these technical qualification challenges. With this, each party involved would be responsible for investing and empowering its own human resources in an optimized and specialized way. This is an opportunity to stimulate the formation and consolidation of new niche markets and jobs. In addition, it allows the reintegration into the labor market of professionals who have already worked in the urban passenger transport sector and have been affected by the crisis in previous years.

Expanding the articulation between cities and civil society to promote the exchange of knowledge and professional training is an opportunity for different segments of society to participate in the transition. This is the case of the National Platform for Electric Mobility (PNME), which brings together academics, the productive sector, and civil society to support the formulation and implementation of electromobility policies; and the initiative Transformative Urban Mobility Initiative (Tumi) E-Bus Mission, which provides mentoring to some cities in the development of pilot projects and planning for the implementation of fleets at scale. Mentoring activity differs from technical advice; it assists in executing projects throughout the process, seeking to solve the identified problems and forward respective solutions on demand.

PNME and Tumi E-bus Mission are two initiatives that provide technical support to cities in the association of electromobility and help to promote greater articulation between them. PNME brings together more than 30 institutions, including public agencies, private companies, academic institutions, and civil society organizations. The main objective is to exchange knowledge so all members can access what is most modern in electromobility. For example, the Electric Bus Working Group focuses on the debate and the proposition of public policy instruments and the regulation of electromobility at the national level. The group's vision is to strengthen a network of knowledge that suggests actions and can change the perception of cities to favor the transition.

The Tumi E-Bus Mission, created in 2019, supports transition initiatives in 20 cities. It is a multi-institutional action formed by organizations such as C40, WRI, ITDP, GIZ, and UN-Habitat, among others. Tumi also acts as a facilitator —that is, it offers alternatives, paths, and responses to the challenges cities face in implementing electric fleets. The goal is to support 100 cities by the end of 2022; by 2025, another 500 cities are expected to join the transition. Another ambitious goal is to have 100,000 electric buses in circulation worldwide by 2025.

Including the companies responsible for commercializing and distributing electricity in this governance network is essential. New business arrangements can be negotiated to enable a more efficient and economical electric bus operation, such as the free energy market. It is a business environment where participants can freely agree on all commercial conditions, such as supplier, price, amount of energy contracted, supply period, and payment method. In this environment, for example, negotiate the price to be charged for the electricity needed to charge the batteries directly with the concessionaires and in a personalized way, according to the service demands, which mitigates the risk of rate variations.

Figure 8 – Electricity supply capacity is a financial variable to be considered in the total cost of ownership of electric buses

Source: Canva (free database, s.d.).

For the implementation of tests and pilot projects and the realization of a large-scale transition for electric buses, it is necessary to evaluate and understand the energy sources that feed the process, the necessary electrical infrastructure, and the capacity of the local electricity grid. This can be a problem in many countries due to their dependence on fossil fuels for power generation. However, in the case of Brazil, the energy matrix is predominantly from clean sources (hydroelectric, photovoltaic, wind, and biomass, for example), which makes electromobility potentially more sustainable.

Since 2010, the country has significantly increased the installed power of wind, solar, and biomass power plants. In addition, many Brazilian cities have high rates of insolation, especially those in the Northeast, Midwest, and Southeast, which allows bus batteries to be favorably powered by charging systems with photovoltaic solar panels and greater energy efficiency [37].

Studies by CPFL Energia [38] in 2018 show that the increase in electricity consumption would vary between 0.6% and 1.6% if the share of electric vehicles in the Brazilian fleet in 2030 is 4% to 10%. This would lead to little but significant impact on the country's electricity distribution network. The additional charge would be entirely absorbed by the current capacity of the electrical system. In the tests carried out by CPFL, even if up to 5% of electric vehicles were incorporated into the total fleet, 80% of the distribution networks would not present any problem.

In the case of systems restricted in the electricity grid or seeking savings, many cities worldwide choose to charge vehicles during off-peak hours and/or make agreements with electric power companies to access differentiated rates [39]. The case of Rio de Janeiro is worth mentioning. In a feasibility analysis conducted in 2019 for the Civil House of Rio de Janeiro, within the framework of the Electric Bus Working Group created to support the city, the EPE Electric Bus Technical-Economic Assessment Tool was used (see item 6.1.3).

The results showed that one of the main financial obstacles to implementing conventional, Padron, and/or articulated electric buses was the value of the electricity rates. According to the study, the energy distribution company Light had the highest rates among all Brazilian distributors (R$ 0.34/kWh), directly impacting acquisition and operation costs. The conclusion is that adopting the system would only be interesting and financially viable if the values were re-agreed.

In Brazil, there is already a modality created by the Brazilian Electricity Regulatory Agency (Aneel) to promote energy consumption outside peak hours through lower rates entitled "White Rates." This differentiated billing method can allow operators also to have greater control over the distribution of energy demand [40].

Another common strategy has been the battery bank for stationary energy storage, known as V2G (vehicle to grid). In this system, owners of electric vehicles and/or electric bus operators charge their batteries during periods of low demand and later resell the power to the electricity grid at peak times.

As has been demonstrated, cities' biggest challenges in implementing electric fleets are still high initial costs, ranging from US$260,000 to US$475,000 in Latin America, especially for acquiring vehicles. In addition, financial barriers are even more challenging for bus transport systems financed by tariff collection (the most common model in Brazil). Because they depend on a balance between revenue and costs, improvements and transformations in the service are almost always subject to increased passenger demand. Reforming the urban mobility system as a whole provides for the implementation of measures that boost public transport by electric buses also from the disincentive to use the car, whose environmental, social, economic, and sanitary impacts significantly affect the population, without distinguishing private car drivers from users of public or active transport. The funds raised from the collection could be transferred to an "electromobility fund" that supports the municipalities to cover expenses with the fleet's operation, maintenance, and modernization. This is a valuable opportunity for cities to enhance the benefits that a robust investment in electric fleets can provide to the population, making it faster, more reliable, and attractive to new users.

Finally, more than 80% of Brazil's electricity generation sources are renewable. This is a valuable opportunity for cities to take advantage of these clean and sustainable environmental resources to manage their fleet, helping the country position itself as a world reference in 100% emission-free electromobility.

2.

SOCIAL, ENVIRONMENTAL AND ECONOMIC IMPACTS

This chapter aims to explore the possible positive and negative externalities from the social, environmental, and economic points of view related to the support of electromobility in public transport at a national and international level, as well as the potential ways to mitigate the resulting negative impacts. Table 4 presents a synthesis of these potential positive impacts.

Table 4 – Synthesis of environmental, economic, and social impacts and respective benefits

Types of impacts	Benefits
Environmental	• Switch to clean energy sources; • Improving air quality by reducing local and greenhouse gas emissions; and, • Reduction of noise pollution.
Social	• Improving the quality of life of the population; • Better working conditions for bus drivers; • Generation of opportunities in the labor market; • Expansion of accessibility for vulnerable users; • Reduction of negative externalities related to public health; • Reduction of congestion if electromobility is integrated into a policy of medium and high-capacity corridors; and, • Political benefits related to citizens' perception of improving public transport infrastructure.
Economic	• Promoting competitiveness among operators, suppliers, and manufacturers, among others; and, • Lower costs with the maintenance and operation of fleets.

Source: Own elaboration.

From these perspectives, an in-depth reflection is presented on how electrification can improve the quality of public transport in the country and the data needed for cities to monitor and evaluate the expected impacts of buses. In addition, the expected cross-sectional impacts related to accessibility and public health by gender and race are described and characterized; for the labor market; atmospheric quality in the face of reverse logistics care; and the promotion of industrial activity, considering the latest and most emerging technologies.

2.1 ENVIRONMENTAL IMPACTS

The World Health Organization (WHO) estimates that air pollution accounts for 4 million premature deaths yearly and that 98% of children in low- and middle-income countries are exposed to air pollutants. With the adoption of electric buses, cities can drastically reduce emissions and noise caused by combustion engines, improving the quality of life of the population and the environment, especially in large centers, where more people depend on buses as a means of transport [41].

Emissions potentially avoided by battery electric buses are "local" or "global." The former directly impacts the area where conventional diesel buses circulate and fundamentally affect the population´s health. Table 5 presents some of the negative impacts on health and air quality that can be avoided by replacing the diesel fleet with electric ones.

Table 5 – Harmful effects avoided by electrification, considering the main local vehicular pollutants.

Local pollutant avoided	Impact avoided
CO (carbon monoxide)	It acts in the blood, reducing oxygenation, and may cause death after a certain period of exposure.
NOx (nitrogen oxides)	Formation of nitrogen dioxide, photochemical smog, and acid rain. They are ozone precursors.

Local pollutant avoided	Impact avoided
HC (hydrocarbons)	Fuels not burned or partially burned form smog and carcinogenic compounds. They are ozone precursors.
MP (particulate matter)	It can penetrate the body's defenses, reach the pulmonary alveoli and cause irritations, asthma, bronchitis, and lung cancer. In addition, it causes dirt and degradation of properties near the transport corridors.
SOx (sulfur oxides)	Ozone precursors forming acid rain and degrading vegetation and properties, besides causing various health problems.

Source: Own elaboration, adapted by Carvalho (2011, p. 20) [42].

Data from 2019 showed that inhaling the air of São Paulo is equivalent to smoking five cigarettes derived from tobacco per day, given the level of pollution caused by carbon dioxide (CO_2) and particulate matter (PM) [43]. This concentration is particularly high around the bus corridors, a primordial infrastructure for transporting many passengers from the city. In addition, about 12% of hospitalizations for respiratory diseases in São Paulo are attributed to the pollutants described in table 5 [44].

In turn, noise pollution is responsible for insomnia and mood disorders, in addition to causing hearing damage and anxiety disorders [45] The simple "ignition" of the combustion engine generates noise with high decibels. In contrast, the technology used in electric motors has the advantage of being silent, representing a benefit the cities can offer to users, drivers, and neighborhoods through which vehicles circulate.

On the other hand, the "silence" of electric buses could cause road safety problems [46]. One way to mitigate this impact is to implement graphic signs and road safety sound warnings on sidewalks and crossings for people with hearing and visual impairment. For example, in 2019, Transport for London (TfL), the body responsible for the transport system in London, implemented equipment with a recognizable sound alert that would help draw the attention of people with visual deficiency or partial hearing impairment (in addition to other pedestrians and cyclists) to the presence of electric buses and thus avoid accidents [47].

An electric bus generates about 5 decibels less external noise during engine acceleration than a diesel vehicle and 7 decibels less than natural gas-powered buses. The introduction of electric buses can improve the comfort of users and the working conditions of the people who drive the buses [48].

The substitution of the diesel bus fleet with electric ones will significantly impact GHG emissions reduction in urban environments, but it is crucial to analyze the emissions reduction throughout the production and usage chain. The electricity generating matrix to power the bus battery must be clean, which gives Brazil a comparative advantage over other countries. The matrix can be enhanced by having hybrid plants of small and medium size, which use more than one type of source for generating electricity, and preferably that produce electricity from wind and solar energy (which has good adaptation in small distributors). Expanding investment in these technologies may, eventually, encourage a production chain of electric buses closer to carbon neutralization.

One advantage for Brazil is that we have one of the cleanest energy matrices in the world, with more than 80% of electricity from renewable sources. Wind power already accounts for more than 70% of new power plants created in 2021, and solar energy generated by small power plants grew by more than 2,000% between 2018 and 2021 [49].

The sustainability certification of lithium-ion batteries is also another environmental factor to be analyzed since their production and recycling are more intensive in raw materials than the production of traditional combustion engines. By 2022, most lithium was extracted from hard rock mines or underground brine reservoirs, predominantly in the South American Triangle formed by countries such as Argentina, Chile, and Bolivia. However, part of the energy used to extract it from hard rocks and process it still comes from fossil fuels: for every ton of lithium extracted, 15 tons of CO_2 are emitted. For comparison, each ton of CO_2 represents the same as a gas-powered car would emit, running about

4025km. In addition, the production of lithium-ion batteries implies using high volumes of water at the risk of contaminating and depleting natural reservoirs [50].

Over 12 years of service life, using an electric bus instead of a diesel bus can reduce operating emissions by 1,690 tons of carbon and 10 tons of nitrogen oxides. On average, considering the life of battery-powered vehicles in the U.S., they emit 33% fewer GHG emissions, 93% less carbon monoxide, and 32% less black carbon than vehicles with internal combustion engines. In Latin America, replacing the annual acquisition of conventional buses with BEBs could reduce CO_2 emissions by more than 5.7 million tons each year and by 124,000 tons of nitrogen oxides [51].

Some solutions to mitigate the emissions' impact and potential contamination risks in the battery production chain are operational improvements and proper usage training to extend their useful life. In 2022, a lithium-ion battery lasts an average of 15 years. Battery life is measured by the number of cycles it can complete or by the temporal durability stipulated by the manufacturer. When storage capacity is below 80% of the initial value, their performance is inappropriate for use in the operation of electric buses.

Driver training is a way to extend battery life. The pilot's driving at regular speeds and avoiding abrupt acceleration ensures greater energy efficiency of the batteries and expansion of the autonomy via regenerative braking. When they reach the end of their service life for operation in electric vehicles, manufacturers have used batteries for stationary energy storage. This is a technology in continuous development by the industry to strengthen the supply of electric vehicle charging at times of higher demand, for example. It has already been tested in China and the United States [52].

2.2 SOCIAL IMPACTS

Most low-income communities rely on walking and cycling trips to access public transport on their daily mobility. The social groups most benefiting from electrification are also the most vulnerable from the point of view of mobility —low-income people, black people (especially women), people with disabilities, the elderly, and children. The poorest communities are the ones that usually suffer the most traffic accidents and health complications related to poor air quality, aggravated by the difficulty of accessing health equipment [53]. With the reduction of local emissions from traffic and noise pollution in these neighborhoods, the environment improves for everybody, and the way to public transport becomes more pleasant. Another significant benefit is the improvement of the quality of service, especially if adopting these technologies prioritizes the traditionally more deficient bus lines in safety and comfort. Often, these bus lines run in the outlying neighborhoods and/or are lines that connect these neighborhoods to the center.

The elderly are also direct beneficiaries of electrification due to low immunity. There are growing indications that pollution caused by the movement of diesel buses contributes to accelerating dementia, for example. In addition, the elderly are more vulnerable to infectious diseases, the means of transmission which occur mainly through the air [54]. Children, in turn, are exposed to indoor and outdoor air pollution. They are particularly vulnerable in the early years of life when the lungs, organs, and brain are still developing. Because they have a faster respiratory rate than adults, they inhale more air and, consequently, more contaminated air [55]. Moreover, in some neighborhoods, children spend much time away from home playing and practicing activities in a potentially toxic environment for their healthy development.

Figure 9 – Women represent just over half of the people who use public transport by bus and are the most exposed to polluted air (especially black women and those living in the suburbs)

Credit: Combat environmental racism.

Brazilian women are significant users of transport by bus. For example, in Belo Horizonte, 80% of the people who use buses are women [56]. In São Paulo, the study Research on Habits and Intentions of Use in the Post-Pandemic, developed by SPTrans in 2021 [57], showed that 57% of the passengers were young and black women of class C, with complete high school education, occupations in the trade sector and average family income of R$ 2.4 thousand.

This exposure does not derive only from the long paths that usually need to go. They also become contaminated when they wait for a long time at pickup points, when "trapped" inside vehicles on days of storm and flooding, or when they work as drivers and are directly subject to the thermal, audible, and atmospheric discomfort of conventional vehicles.

Until they reach their destination locations, women are subject to breathing polluted air for approximately 38 minutes in a row, considering the average travel time in several metropolitan regions of Brazil. This is equivalent to an exposure of approximately 1h20min for each complete round trip, according to data from the National Household Sample Survey (PNAD/IBGE) for metropolitan regions Demographic census/IBGE for capitals.

Black women also reside farther from public transport stations and face the most difficulties accessing the city's opportunities. Only 8.5% of black women in the Metropolitan Region of Fortaleza live near a medium and high-capacity transport infrastructure, for example. In the Metropolitan Region of Belo Horizonte, this percentage drops to 6.8%. The highest percentage in Brazil of black women living near a medium and high-capacity transport route — in the Metropolitan Region of Rio de Janeiro — does not exceed 15% [58].

The replacement of conventional buses with electric buses would generate substantial advantages for the well-being of this portion of our society, which is equivalent to 27.8% of the Brazilian population (according to data from the IBGE National Household Sample Survey 2018). Furthermore, an electrification project associated with unique corridors would also make commuting faster, dignified, and more reliable, considering their transport needs. In addition, many women have to make several trips at off-peak times to take care of household chores, childcare, and work assignments.

However, cities should be aware that systemic improvements are needed to maximize the benefits of electric buses. There are essential measures that cities should consider to mitigate the negative impacts suffered by this target audience in parallel with fleet replacement:

- Regular qualitative surveys of user satisfaction can help understand how electric bus service meets (or not) their needs and yearnings. Consequently, cities can introduce any additional adjustments and improvements consistently.

- Mobile internet coverage inside electric buses and at pickup points allows passengers to be distracted and/or maintain adequate communication with children, stepchildren, relatives, and friendly people along the way — especially for emergencies.

- Effective electric bus tracking system helps provide users with real-time service monitoring, with greater predictability of waiting at pickup points.

- Shelters suitable for waiting and improved street lighting conditions around bus stops can provide comfort and help mitigate any threats to women's safety on the route between the bus stop and their home (and vice versa), especially at night.
- Implementation of communication channels and women's care centers are necessary as instruments of care and support to women, especially in situations of sexual harassment and other types of violence. They should be composed of multidisciplinary teams of women social workers, psychologists, and lawyers in stations and public transport terminals.

Figure 10 – The absence of the front engine in electric buses directly benefits the quality of the working day and the drivers' health.

Credit: Pedro Bastos, ITDP Brasil (2021).

Bus drivers are part of a category essential to the proper functioning of cities. However, they are also among the most affected by the employment crisis in the urban passenger transport by bus sector caused by the Covid-19 pandemic. In 2020, the sector lost 67,025 jobs nationwide, according to data from the National Transport Confederation [59], which includes drivers, collectors, and diesel vehicle maintenance personnel, among other functions. In September 2020, the balance remained negative: -20,470. In addition, drivers and collectors are the most victimized category: between April 2020 and March 2021, people working in these roles led the ranking of terminations of employment contracts by death.

Using less noisy vehicular technology has invaluable potential to improve the quality of their work environment. For example, in 2019, more than 3,500 professionals in public transport by bus in Belo Horizonte suffered hearing loss from exposure to sound pressure levels (SPL) above 82 decibels for at least eight hours a day [60]. The maximum allowed by NR 15, the standard that regulates situations of unhealthy workers, is 85 decibels. In addition to increased acoustic comfort, electric buses offer more thermal comfort (the diesel bus engine can raise the internal temperature of vehicles to 50^{0}C), which helps prevent sleep disorders, stress, increased heart rate, high blood pressure, digestive disorders, and headaches.

Another benefit of adopting electric buses is the possibility of re-employing drivers and collectors in more qualified functions. In terms of operation and maintenance, electric vehicles are quite different from conventional buses. Therefore, the experience of current drivers and collectors in traffic and other activities related to public transport is a competitive differential. In addition, prioritizing these people means offering them the opportunity for the most significant compensation in the short and medium term.

In this sense, when planning the adoption of electric fleets, cities can enable initiatives that cost the retraining and requalification of these workers, aiming at their reintegration into the labor market in green jobs associated with transport [61].

Several important training initiatives were made in partnership with public, private, and academic organizations. An example is the graduate program in hybrid and electric vehicles offered by the National Service for Industrial Training (Senai-PR and Senai-SP), a reference entity for the education of professionals in the automotive sector. In Paraná, the Senai Sustainable and Intelligent Mobility Center (Curitiba Industry Campus) is part of the Paraná Federation of Industries System and, in partnership with the Research Development Foundation (Fundep) and MCTI, promotes a professional improvement course in electromobility (ROTA 2030 - FUNDEP, 2021). The course covers from general aspects of urban mobility to hybrid and electric vehicle components, biofuels, and vehicle electrification safety.

Affordable tariffs are essential to prevent passenger evasion and modal migration, but public transport by bus financing still depends largely on the tariffs paid by users. To increase revenues and finances for the transition to clean technologies, cities are implementing solutions such as leasing spaces for advertising in vehicles, terminals, stations, and bus stops; fees for the movement of cars in some areas of the city; and the implementation of planning instruments that reverse, for the benefit of the community, the financial counterparts paid for interventions in the use and occupation of urban land.

Figure 11 – Volta Redonda pioneered electrifying public transport lines and made them free

Credit: Jornal Destaque Popular (2020).

Volta Redonda, in the interior of the state of Rio de Janeiro, is one of the pioneer cities in the transition. In 2018, it incorporated three electric vehicles into the municipal fleet, subsidizing the service by 100%. Public electric buses are part of the Zero Commercial Rate program. The "zero" is also used as an analogy because it offers the population a vehicle with zero emissions of pollutants, besides being silent and comfortable. Unfortunately, Volta Redonda is the home of a steel mill, which generates environmental impacts. Therefore, the city must take environmental compensation for the wear and tear caused to the municipality's population, fauna, and flora [62].

The vehicles of the Zero Commercial Rate program operate on two lines between the city's main shopping centers. In addition, electric buses are trendy in the city, making Volta Redonda an inspiring example for medium and small municipalities that wish to enable a fair and universal electromobility system. In 2019, Tarifa Comercial Zero was part of the winning project of the "Prefeito Empreendedor" award at the national level in the category "Productive Inclusion and support to individual microentrepreneur" granted by Sebrae [63].

In the following chapters, some fundraising possibilities are presented in more depth from the planning directions and the definition of a business model.

In cities such as São Paulo, the Onerous Grant of the Right to Build, also known as "created soil," is an instrument that authorizes the people who own real estate to build above the limit established by the coefficient of basic use by paying a financial consideration to the city hall. This financial contribution is intended for the Urban Development Fund, used to fund projects of social interest —for example, public transport, bike lanes, and sidewalks. In fleet transition, cities can create similar mechanisms to expand their revenues, including creating a fund dedicated exclusively to electromobility through value-capture instruments.

2.3 ECONOMIC IMPACTS

One of the concerns of cities that want to invest in electromobility is the increased expenses with fleet management, operation and maintenance, and capital risk. On the other hand, economic impacts can be positive in the medium and long term compared to the same expenses to maintain a diesel fleet.

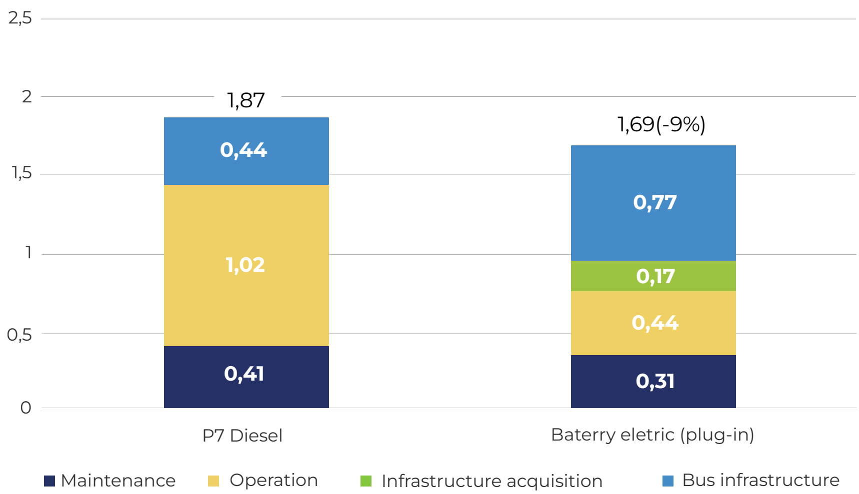
First, battery electric buses can be more financially efficient because they require less energy per kilometer than diesel buses (comparing equivalent energy and fuel).

A feasibility study conducted for the city of Monterrey (Mexico) found that, with 50 kWh (the energy equivalent to 5 liters of diesel or 4.5 liters of CNG), a battery electric bus has a range of 30 km, while a diesel bus travels 12 km, and a bus on CNG, only 8 km [64].

Although the initial costs can reach twice that of a diesel vehicle, energy costs per kilometer traveled are half [65]. This is partly due to electricity rates being lower than the amount charged per liter of diesel and the more efficient energy conversion on the go. This is one of the main factors that make electric buses a more advantageous and economical option in the medium and long term.

In addition, the operating and maintenance costs of battery electric buses may be lower than those of diesel buses, as the electric propulsion system does not require the same type of overhaul as a combustion engine, nor does it require frequent replacement of parts after a certain period. For example, figure 12 shows that the TCO for a fleet in São Paulo is 9% lower than a diesel model [66].

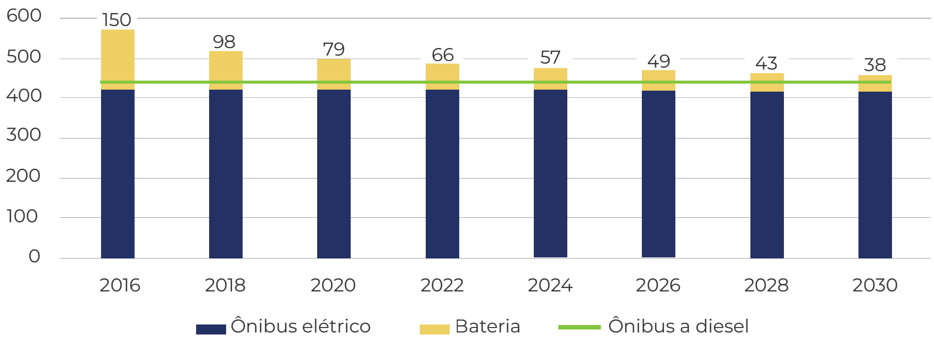
Figure 12 – Total cost of ownership (over ten years) of conventional and electric buses in São Paulo in 2018 (in millions of reais)



Source: Adapted from Slowick *et al.* (2018, p. 14) [67].

Although the costs of acquiring an electric bus are higher, which can range from US$260,000 to US$475,000 in Latin America, operating expenses for diesel buses are twice as high. Comparing the two TCOs shows discrete variations between both technologies but with relative infrastructure acquisition and maintenance advantages [68].

Figure 13 – Forecasting costs of electric and diesel buses in the European context (in thousands of U.S. dollars)



Source: C40 Cities; WRI (2018) [69]. Note: Battery electric bus with 250 km of autonomy. Inicial price of the battery is 600 dollars/kWh.

According to the trend scenario considered in the chart for Figure 13, despite the initial barrier, the purchase price of chassis and bodywork for electric buses tends to fall by 2030. This may not necessarily be considered a trend for other countries, but it is an important indicator. The total value of an electric bus includes the vehicle and its components, where the battery is the main one, which has challenging and determining costs for the final value. Therefore, the value of the vehicle tends to remain constant over time.

The battery, in turn, is the component that can most favor the cheapening and, consequently, the gains in scale. With technological updates and continuous collection of information about its operation, the expectation is for batteries to become increasingly accessible. In 2016, a lithium-ion battery's cost was an average of US$150,000, but by 2021 it was almost half. Recent data released by Bloomberg [70] revealed that the change in battery price in a decade was 89%. In this context, competitive parity with diesel buses should be achieved between 2026 and 2030. In this sense, despite being an investment that still requires a large volume of resources, the projections show medium and long-term risk mitigation.

3.

ELECTROMOBILITY PLANNING

This chapter presents the initial planning recommendations for elaborating projects and proposals for structuring electromobility by buses. The objectives are to classify the different stages of planning of the cities and indicate actions and procedures to assist them in the more efficient adoption of electric buses on a large scale, considering technical, institutional, financial, social, and political issues of the municipalities.

3.1 POLITICAL AND REGULATORY PATHS

Nationally, the National Climate Change Policy (Law No. 12,187/09), the National Urban Mobility Policy (Law No. 12,587/2012), and the Statute of the Metropolis (Law No. 13,089/09) provide basic guidelines for all states and municipalities on how to mitigate the adverse effects of global warming and low air quality and plan modes of transport, towards integrated sustainable development.

On a municipal scale, integrated urban development (PDUI), urban mobility plans, and environmental legislation indicate how cities should plan their transport systems, but it is not yet common to find electromobility guidelines in these documents. However, some plans and legislation may include mechanisms that favor technological changes that guide the fleet's transition to cleaner technologies. In addition, cities that make an emissions inventory and set reduction targets have more precise political and regulatory paths capable of guiding the planning of electric bus systems. Table 6 presents the legal frameworks for urban mobility in some Brazilian cities by 2021 and indicates which ones have inventories and targets.

Table 6 – Legal frameworks for urban mobility in some Brazilian cities by 2021

City	Legal framework	Does it have an emissions inventory?	Does it have an emissions reduction target?
Brasília (DF)	2020 — Urban Mobility Plan 2021 — Mitigation Plan to Reduce the Emission of GHGs of the Main Issuing Sources in the Territory of DF	2016	Yes
Belo Horizonte (MG)	2006 — Decree n.º 12.362/2006: Municipal Committee on Climate Change and Eco-Efficiency 2011 — Municipal Urban Mobility Policy and Municipal Climate Change Mitigation Policy 2012 — Municipal Plan to Reduce Greenhouse Gas Emissions 2014 — Master Plan, with the forecast of reducing emissions of polluting gases as an environmental target associated with mobility	2008	Yes
Campinas (SP)	2019 — Urban Mobility Plan 2019 — Mobility Development Fund 2020 — Municipal Policy to Combat the Impacts of Climate Change and Air Pollution of Campinas	2019	No
Campo Grande (MS)	2009 — Transport and Urban Mobility Master Plan	No	No
Curitiba (PR)	2008 — Municipal Plan for Environmental Control and Sustainable Development 2008 — Mobility and Integrated Transport Plan 2020 — Climate Change Mitigation and Adaptation Plan	2016	No

City	Legal framework	Does it have an emissions inventory?	Does it have an emissions reduction target?
Florianópolis (SC)	2018 — Integrated Urban Development Plan of Greater Florianópolis (PDUI)	No	No
Fortaleza (CE)	2015 — Mobility Plan 2017 — Low Carbon Urban Development Policy 2017 — Municipal Environment Policy	2019	Yes
Guarulhos (SP)	2019 — Urban Mobility Plan	No	No
Manaus (AM)	2015 — Urban Mobility Plan	No	No
Porto Alegre (RS)	2019 — Urban Mobility Plan	2015	No
Rio de Janeiro (RJ)	2011 — Municipal Policy on Climate Change and Sustainable Development 2019 — Sustainable Urban Mobility Plan 2021 — Sustainable Development and Climate Action Plan of the City of Rio de Janeiro, developed with the support of UN-Habitat and aligned with the 2030 Agenda 2021 — Pollutant Gas Emissions Elimination Program	2015	Yes
Salvador (BA)	2015 — Municipal Environment and Sustainable Development Policy 2018 — Sustainable Urban Mobility Plan	No	No

City	Legal framework	Does it have an emissions inventory?	Does it have an emissions reduction target?
São Paulo (SP)	2009 — Climate Change Policy 2015 — Urban Mobility Plan 2018 — Climate Action Plan of the Municipality of São Paulo 2020-2050 2021 — Duties of the Executive Secretariat for Climate Change (Seclima) and coordination of the Secretariat for the implementation of all climate-related policies	Yes	Yes
São José dos Cam-pos (SP)	2016 — Municipal Urban Mobility Policy Under Development — Municipal Climate Change Mitigation and Adaptation Policy	No	No

Source: Own elaboration. Adapted from IEMA (2020b) [71].

Depending on the local context, the degree of integration between these actions may vary regarding cooperation and orientation to sustainability. Because of this, municipalities should consider the planning of electric buses as an opportunity to develop effective guidelines for Transit Oriented Development (DOTS).

Figure 14 – in São Paulo, the bus corridor of Avenida Rebouças complies with some of the principles of DOTS, ensuring that the population has quick access to opportunities in the south and west of the city

Credit: IEMA (2019).

Transit Oriented Development (DOTS) has guided urban plans and projects in several cities around the world. This approach stimulates the creation of territories that take advantage of space efficiently, promoting urban vitality and diversity and ensuring the proximity and integration of people with other areas of the city through transport. DOTS is based on the following principles:

1. Compact the urbanized area to shorten distances;
2. To deepen the territorial occupation in a manner corresponding to the capacity of public transport;
3. Mixing land usage to stimulate demographic and income diversity;
4. Reprioritize the distribution of road space;
5. Integrate the various regions through quality public transport systems;
6. Create neighborhoods that stimulate walking; and
7. Prioritize mobility networks by bike.

In parallel with the activities related to the replacement of the fleet itself, including a political-regulatory path in the planning schedule allows the elaboration of actions that review the priority of distribution of the road space, providing for the coverage of the service at scale and a modal integration of quality that allows users to access different parts of the city safely and quickly. To assist planning, Mobility Management (GdM) strategies can greatly help cities perform this planning more consistently and sustainably (GdM strategies are further developed in section 3.2. Institutional and financial aspects).

Figure 15 – in Brussels, efforts to encourage a shift to public transport also help make streets more pleasing to people

Credit: Eo Naya, Shutterstock (s.d.).

Mobility Management (GdM) is a set of strategies that seek to increase the efficiency of the transport system, making it more inclusive and socially fair. To this end, they propose to reduce traffic and the use of private vehicles and stimulate modal migration to public transport and active modes (cycling and walking). Effective Measures of GdM aim to influence the behavior of road space users, guiding how, when, and where displacements should occur. However, discouraging the use of cars is still challenging, even in places with an adequate supply of alternative modes of transport to cover motorized travel. To meet this challenge, GdM uses measures that redistribute the road space equally and price the use of the car. The funds raised can feed a public electromobility fund to finance the electric fleets and corresponding expenses [72].

From the impact that cities want to generate with investment, it is interesting that they develop scenarios on how they should act to enable transformation. The Avoid-Shift-Improve (A-S-I) planning approach is a recommended strategy so that each municipality can understand what it needs to avoid, change and improve to promote the adoption of electric buses. This approach includes three integrated pillars for public transport, as illustrated in Figure 16.

Figure 16 – integrated approach of transport planning: Avoid-Change-Improve

Source: Own elaboration.

Avoiding refers to the abandonment of behaviors and decisions that reiterate the inefficiency and low inclusiveness of the mobility system. This step provides for the diagnosis of the performance of the city's mobility system. Some indicators and evaluation paths are, among others: identification of the population's transport behaviors; matrix of the modes of transport of the municipality; bus fleet by vehicular technology; average travel time per transport modality; profile of transport infrastructure and percentage of people residing near medium and high-capacity transport routes (including income, race and gender cuts). From this diagnosis, cities have a way to map the main threats and define actions to avoid them. For example, it is known that incorporating electric buses is a fundamental measure to avoid the maintenance and expansion of polluting fleets. Additionally, with evidence at hand, cities have more strategic tools to plan the distribution of the electric fleet according to the most critical points identified.

Change refers to the design of actions to improve the efficiency of displacements. The orientation is to guide a modal shift based on lower energy consumption, encouraging people to use greener and more efficient modes of transport. For a policy focused on electric buses, effective actions are recommended to reprioritize the distribution of road space. However, these changes still pose challenges for many municipalities, which have expanded from motorized transport infrastructures that, to this day, still shape the behavior of the population. Cities interested in implementing bolder MDG measures can catalyze these changes.

Improving refers to the strategy to make public transport by electric buses more attractive. It is necessary that attributes such as "comfort," "safety," and "reliability" make public transport by electric buses an intentional choice for travel. This pillar includes the planning of instruments to verify the satisfaction of users and professionals involved and vehicle performance evaluations.

After mapping out the aspects cities need to avoid, change, and/or improve, they must choose the most consistent and pragmatic planning path. The preparations range from initial conversations with stakeholders indispensable to governance to the planning of the most crucial routes for the introduction of technology.

3.1.1 Potential partners

Identifying potential stakeholders who can participate in the governance of the operation is part of the planning preparations. From this initial articulation, cities plan and provide an appropriate business model. However, it is important to emphasize that many of these stakeholders initially addressed may not remain linked to the project in the medium and long term. For example, a city council can partner with a manufacturer to conduct a pilot project. However, after the evaluation of the performance of the vehicles, one can conclude that the models offered are not compatible with the challenges faced by the city. Another possibility of partnership occurs with network operations, such as the National Electric Mobility Platform. PNME brings together more than 30 institutions, including government agencies, industry, academic and civil society, enhancing the exchange of information between partners and consolidating learning and skills training mechanisms. In this sense, this initial phase enables a starting point and not necessarily determining commitments.

3.1.2 Planning to receive electric buses

Every city can operate electrical routes. However, each follows its own path for its adoption. **A cautious way to assess how each municipality or metropolitan region needs to prepare is through pilot projects.** From this, the planning can indicate phases guided by an understanding of the routine behavior of vehicles on test routes.

The first phase is intended to plan the route where the bus will circulate. Cities can draw a new route or use an existing route. Route planning should be integrated with location planning of charging infrastructures and guided by equality and inclusion criteria. For example, planning from the beginning a route that ensures accessibility for low-income people, especially women, is crucial to balancing the distribution of benefits with a focus on who most depends on public transport. Another criterion for planning routes is the prioritization of more polluting lines. Prioritizing the most critical lines based on these criteria is a strategy to maximize the benefits of the transition until the service is scalable.

Figure 17 – Planned route for a pilot project in Rio de Janeiro benefits the region of Madureira, 20 kilometers from the Center

Credit: Pedro Bastos, ITDP Brasil (2021).

The planning of the Rio de Janeiro pilot project is an example of how cities should prioritize routes that favor the population most affected by the conventional public transport system. The city planned an experimental route that would serve the population of Madureira in the North Zone. Located 20 kilometers from downtown Rio, the region is predominantly inhabited and frequented by a medium- to low-income black population, besides being an important commercial and service hub. Adopting electric battery vehicles in these neighborhoods is strategic to compensate for the environmental discomfort affecting residents' well-being. The thermal sensation varies between 40 °C and 50 °C, especially in summer.

The second phase is to plan the performance evaluation of drivers and technicians to deal with vehicles and infrastructure properly. In this sense, the initial phase should not predict the presence of passengers and must occur under the supervision of trained personnel. The formation of partnerships with manufacturers is an alternative for training and basic assistance during the pilot and the first year of operation of the vehicles. In addition, this phase should provide for charging experimentation of vehicles, paying close attention to real-time charging of the battery, corresponding to the availability and capacity of electricity and the location of garages and terminals.

The third phase should monitor vehicles' behavior when driving on an experimental route. This behavior depends on topographic or road conditions, specific temperature conditions, and other weather events. When contemplating the passengers' transportation, it is also possible to assess the brake and the gear of the engines in the pickup and drop-off stops and check to what extent the battery autonomy is preserved (or not) throughout the service. Although pilot projects have a specific operational role, they allow managers to identify necessary actions at tactical planning levels. The tactical level is responsible for any corrections necessary for failures verified during the operational test. From the performance results, managers can rearticulate the stakeholders indispensable to the operation, define responsibilities and plan the regulation for a permanent fleet.

3.1.3 Planning of contracts for the adoption of electric buses

Aware of what they need to do and the technical specificities of the vehicles and infrastructure necessary to enable the proper operation of electric fleets in each urban context, cities reach the stage of service regulation. This implies creating a specific regulation for electric buses or, ideally, reviewing the current regulations to influence the gradual replacement of the conventional fleet with a cleaner and more sustainable one. One of the main recommendations is to provide financial incentives that increase the competitiveness of electric buses. Specific business models can also speed up the transition.

Concession contracts determine technical and operational questions about how the fleet will be made available and how the service will be provided. National and international experiences demonstrate good practices during the planning of the preparation/ review of contracts:

- **Separate supply and operation contracts to define deadlines consistent with the type of service offered**
  Mostly, the contracting models in force in the country grant private companies the system's operation, including investment in the fleet, with the government responsible for its planning and supervision. On the one hand, this dishonors fleet management and operation; on the other hand, it holds only one of the parties involved accountable for innovations and quality of service. Planning the sharing of activities and risks gives greater cooperation and responsiveness to the economic, social, and environmental demands of an electric bus project, which can improve the quality of service. We deal with more on the subject in chapter 5.

- **Establish deadlines for the provision or ownership of vehicles for electric buses**
  Due to the high cost of acquiring electric vehicles, a period of 15 years is more compatible with the amortization of the investment. It also corresponds to payback, the time for the cost of purchase of the electric vehicle to be fully recovered.

- **Stipulate operating times of less than ten years to ensure the incorporation of innovations and establish greater competitivenes**s
  Operating times of less than ten years encourage operators to plan to ensure innovations following contractual rules.

- **Discriminate, in the notice, the type of technology to be used in the fleet (battery electric vehicle) and other technical specifications, based on the performance evidence collected in the pilot phase**
  Generally, contracts do not define which assets should be acquired (brands and models) but rather the technical specifications to be used in the provision of services. Depending on the assets' profile, there is a considerable variation in the level of detail. The performance evidence collected in the pilot phase can guide the planning of technical specifications that best adjust the operation in the city.

- **Establish and impose fines or penalties related to improving the quality of service**
  About 60% of the contracts in force in Brazilian capitals do not present remuneration criteria capable of generating incentives to improve the quality of service to the user. Bolder initiatives to improve the quality of service may be in the background or end up not being implemented, especially if they are not financially advantageous for operators.

- **Ensure garages and supply sites are covered and airy to prevent exposure of vehicles and batteries to climate variations**
  For safe and efficient accommodation and charging electric buses, cities must plan garages of appropriate size, covered and airy, to avoid exposure of vehicles and batteries to climatic variations.

- **Establish regular training for employees and drivers with a focus on innovative technologies adopted**
  The planning of the training of employees and drivers should consider the specific requirements of the type of technology. Until 2021, São Paulo was the only municipality that had planned a specific training program for technologies or actions to reduce the emission of pollutants. Fortaleza and Belém mention, in their contracts, the need for training to improve the quality of service but do not specify the actions to be taken. In the case of electric buses, planning these measures is essential to ensure a favorable political-regulatory path to fleet expansion.

3.2 INSTITUTIONAL AND FINANCIAL ASPECTS

Even with adopting business models that attract stakeholders from different sectors to make up the sources of investment, cities must be aware of all the expenses involved in the total cost of ownership of electric buses. The dismemberment of these costs in the acquisition, implementation, and support/maintenance allows municipalities to monitor each of the isolated variables, as illustrated in Table 7.

Table 7 – Financial variables in the total cost of ownership of electric buses

Category	Aspect	Description
Acquisition *(buses and components)*	Initial payment/ capital financing	Initial payment, which may come from existing funds or grants. It does not include the financing to be returned.
	Payment(s) of loan(s)/ debt financing	Payment(s) of loans and related interest over the specified schedule.
	Resale value	Applicable only when the vehicle's life exceeds the system's operating time when the option is for purchase.
Operating costs *(operations and maintenance)*	Supply with electricity	Annual expenditure on electricity tariffs to charge batteries.
	Other operations	Annual cost of additional materials required for operations, such as air conditioning.
	Bus maintenance	Annual maintenance cost.
	Infrastructure maintenance	Annual cost of maintaining the charging infrastructure (both on the route and in the garages).
	Review of buses	Bus and battery overhaul costs, e.g., battery replacement in cases of failure before the end of scheduled useful life.

Category	Aspect	Description
Final destination costs	Destination of buses and charging components	If the useful life of the buses does not exceed the operating period of the system, the cost of the destination of vehicles and components shall be foreseen.
	Battery destination	Cost of battery allocation. Manufacturers may be responsible for the disposal if under warranty or a disposal system called a contract.

Source: Own elaboration.

Another variable cost is the current taxation. In Brazil, four main taxes focus on electric buses. Most of them are federal taxes, but they impact the budget of cities:

- **Import Tax (II)**, taxed when the bus enters the national territory when imported, and with a rate for the complete electric vehicle (mounted) of 35%;

- **Tax on Industrial Products (IPI)**, tied to the vehicle's technical specifications and characteristics, ranges from 7% to 25%. The IPI of the lithium-ion battery, for example, corresponds to approximately 15% of the total value;

- **Social Integration Program (PIS) and Contribution for the Financing of Social Security (Cofins)**, which can exceed 15% when added and;

- **Tax on Circulation of Goods and Services (ICMS)**, the only state tax listed, generated when a commodity or service circulates within or outside the state, with a rate of up to 20%[73].

Given the variables presented, many cities may be unable to afford the total cost of electric buses or find that they lack the institutional conditions necessary to attract stakeholders with high financing capacity. On the other hand, planning GdM measures effectively fosters intelligent and effective fundraising to fund and feed the electromobility program.

Some of the most common GdM measures that cities can plan and adapt are:

- **Parking management:** making the administration of public parking more efficient and better monitored can generate revenue for cities. The examples of the Zona Azul (rotating parking system with specific rules depending on the region, day, and time) already implemented in Brazil demonstrate the potential of the strategy to manage spaces on public roads. Outside public roads, the taxation of private parking is a strategy to be considered to ensure that a percentage of profits are passed on to municipalities specifically for investment in public transport. The same can be applied to commercial parking lots. The transfer of the cost to users is optional.

- **Pricing measures with social registration:** the institution of "tolls" for access to certain city areas may restrict some modes of transport and increase segregation. In this sense, it is interesting that cities make a social registration of the population exempt from paying the fees or able to receive discounts depending on their income, place of residence, or unavailability of alternative transport. Social registration acts as a mitigation of a possible expansion of inequities caused by pricing. The viability of the registration should be integrated and validated with other registers possibly existing in the social protection system of each municipality.

- **Taxation for the possession of surplus vehicles:** introducing a charge for possessing additional vehicles (e.g., from the third or fourth private car) is a progressive tax to control traffic volume.

- **Charging of large commercial establishments:** the availability of public transport is decisive for access to shopping malls, supermarkets, and department stores, among others, which depend directly on the consumer public. Therefore, charging a rate on these commercial establishments is a way to raise funds to invest in improvements in public transport and, consequently, increase the accessibility of the population to these places.

Transport pricing has a substantial impact on people's behavior. On the one hand, their implementation and operation are costly and potentially unpopular measures. On the other hand, it can effectively increase revenue, helping to create a specific source of resources to offset upfront costs and ensure gains in scale with electric buses. In addition, they collaborate to improve, maintain or create transport alternatives for people who suffer "restrictions" due to the modality charged.

Figure 18 – Low carbon and congestion pricing districts (pictured in London) are GdM strategies whose revenues can be used by cities to fund electromobility

Credit: Frank Augstein/AP (2020).

In 2003, London implemented a congestion charge to reduce travel time in the city center, increase the reliability of buses and encourage the population to adopt public transport as the primary mode of commuting. The collection zone is 21 square kilometers. In this perimeter, drivers are required to pay a fixed amount (£15 in 2020) to circulate between 7 am and 10 pm every day.

From the outset, the city has undertaken to provide high-quality transport alternatives in return. To this end, it added 300 new buses to the network, distributed in new itineraries, on the day congestion pricing came into force.

By law, revenues are allocated to improve public transport, cycle, and pedestrian infrastructure — an important measure to ensure public support and maintain the quality and reliability of these modes of transport.

- Revenues of at least £100 million (US$129 million) have been generated yearly since 2008. Between 2014 and 2018, revenues exceeded £150 million (US$194 million).
- Between 2002 and 2014, the number of private vehicles circulating within the collection zone fell by 39%.
- Year after year, the average number of bus passengers is around 29,000 during morning peak hours.
- Delays in bus services decreased by 50% [74].

3.3 SCENARIOS FOR SHORT, MEDIUM, AND LONG-TERM PLANNING IN MUNICIPALITIES

Regardless of the institutional, economic, social, and environmental context, cities should remain focused on long-term planning so that initiatives evolve from the pilot project phase and gain scalability and financial sustainability.

This section presents short, medium, and long-term scenarios to guide municipalities' transition processes. The goal is to guide cities, highlighting their current position and how they should evolve to ensure a fleet based on clean and healthy technologies.

3.3.1 Short-term planning

- Identify the best routes to be served by electric buses: for this, it is vital to have at hand technical information, such as distances traveled daily and topography, and indicators and metrics to measure the social impact that the introduction of an electric fleet provides to the population at the beginning of the operation (in item 6.1, some monitoring indicators that the city can adopt are presented);

- Know the existing financing models for the acquisition of infrastructure, vehicles, and batteries: aware of the possibilities available, the city can trace the financial viability of the operation;

- Exchanging experiences with cities that have already implemented electric buses helps optimize resources and explore easier paths to evolve into a fleet at scale. In 2022, PNME and Tumi E-bus Mission are two programs that facilitate the articulation between cities (see item 5.1);

- Review the regulation of public transport and provide for obligations and incentives for the use of innovative technologies through targets, bonuses, penalties, or fines to operators;

- Include GdM strategies to reorganize road space, prioritize pedestrians, cyclists, and electric buses, and implement an electromobility fund that helps fund the service.

3.3.2 Medium-term planning

- Engaging the population in route planning: the definition of itineraries can face technical barriers (for example, the distance from infrastructure and garages). On the other hand, the city must ensure that the demands and needs of displacement are met, and that possible negative impacts caused by the new system are avoided. An ombudsman system can be created or improved at this stage;

- Planning a transition at scale: Initially, the deployment can be started with a few vehicles and then identify the resources needed to expand the coverage of the technology. It is important to map financial stakeholders, banks, and potential investors to expand the source of resources to be incorporated into the project at this stage;

- Evaluating the choice of a more expensive fast-charging infrastructure (e.g., by pantograph or induction) to optimize fleet operation: knowledge gained throughout the first phase and proof that electric buses are efficient and can meet public transport demands are competitive advantages for the city to attract new stakeholders willing to finance more robust arrangements at this stage and in the future.

- Expand the electrical routes and adapt to the new challenges: neighborhoods not yet met in the initial stage and now included in the electrification map may present topographic characteristics unfavorable to the circulation of battery vehicles. The city must reconcile modified operation plans for areas with distinct geographic characteristics.

- Implement congestion pricing measures and/or establish carbon-neutral urban perimeters.

- Monitor the life cycle of batteries and components, providing the appropriate time for technological exchanges and/or updates and respective personnel training.

3.3.3 Long-term planning

- Plan the execution of a 100% electric fleet: ideally, a certain number of diesel or CNG vehicles should be removed from circulation for each electric bus purchased. Replacement should start with vehicles with older technologies. This ensures that the benefits of electric buses are fully provided to users and the population.

- Establish a transparent and broader communication strategy with the city's population and others: there must be a commitment to communicate progress to the public towards the established goals.

- Use the funds raised by the GdM measures to finance the expansion and renewal of the fleet: in this way, the system enjoys financial and environmental sustainability.

4.

BUSINESS MODELS FOR ELECTROMOBILITY

The design, implementation, and management of a business model that financially enables the use of electric buses in any municipality is a key element so that it is possible to materialize the set of benefits detailed in the previous chapters continuously and consistently in the long term. Therefore, this chapter evaluates different business models designed to implement electromobility in public transport by bus. The purpose of this chapter is to support the municipality in choosing institutional and financial paths that ensure the sustainability of the transition to electromobility in the short and long term.

The institutional, contractual, operational, and financial criteria that influence the formulation of business models are addressed. National and international reference cases are analyzed, highlighting positive and negative aspects and potential adaptations to the reality of Brazilian cities. As examples, the experiences of Chile and Colombia with the bus or battery leasing model are examined. In addition, cross-cutting themes are explored on the impacts of energy and infrastructure, governance, the environment, and energy security in formulating business models.

4.1 DEVELOPMENT OF BUSINESS MODELS FOR ELECTRIC BUSES

One of the main challenges experienced by cities is to identify a business model that is appropriate to the level of complexity required by the operation of electric fleets. Table 8 presents the possibility of a business modeling process for electric buses, exemplifying factors that determine how to pay, mobilize capital, and structure implementation.

Table 8 – Planning and possibilities of formulating the business model for electric buses

Investment components	Resource sources	Financial products	Mechanisms for the provision of services
Tangible assets	Investment revenues	Capital	Contracts
Buses and batteries Charging infrastructure Electricity supply infrastructure Additional construction and infrastructure	Usage fees or tariffs Capture of soil value Advertising in the stations and infrastructure Operation savings	Direct or indirect private investors Public investors	Concession of the public passenger transport service Purchase contracts (public and private) Vehicle, battery, and land leasing Leasing for the purchase of vehicles and batteries
Intangible assets	Incentives	Debt	Means of implementation
Safety Efficient localization Reputation of service Sustainability Affordable Research and development	Subsidies Tax incentives Private investors	National Loan - public or private Climate funds' loans Green bonds	Public Private Mixed

Investment components	Resource sources	Financial products	Mechanisms for the provision of services
Processes	Own resources	Credit improvement	Institutional framework
Feasibility studies Infrastructure construction and installation Service operation Professional trai-ning Maintenance	Other areas of government Tax revenues dedicated to elec-tromobility Sale of assets and scrapping	Contingency funds Supply contracts Financing on pre-ferential terms	Plans and goals Regulation and requirements Permissive laws (low carbon zone, green bonds)

Source: Adapted from WRI Brasil (2018) [75].

4.1.1 First step

Developing a successful business model starts with diagnosing the city's public transport system by bus to advance in electromobility.

One must identify the bus lines eligible to receive the technology. The proposed business model should consider the criteria for selecting routes, such as social impacts, urban policies, and attracting new users to public transport.

Once the lines and itineraries to be operated with electric vehicles are defined, a diagnosis of the **technical conditions in the area covered concerning the electricity grid should be made.** It is necessary to ensure that the routes have access to electricity to enable the correct functioning of the technology. Some lines are socially relevant to receiving the technology but can be technically problematic. The business model must identify in advance whether investments in the transmission network are necessary for the charging structures to function correctly and meet those locations.

As electric buses can be adopted to replace the entire fleet, or only part of it (operating in parallel with diesel vehicles), **the size of the fleet of diesel vehicles to be replaced can be calculated**, in addition to the average mileage traveled by electric buses in place of diesel buses.

Finally, all complementary tangible assets should be mapped and quantified to ensure electric vehicles' continuous and efficient operation. For example, how many charging points are needed, and where will they be installed? Depending on local power distribution conditions, one type of infrastructure may work better than another. At this stage, there must be clarity about the most appropriate infrastructure, equipment required, and operating arrangements.

4.1.2 Second step

Once the investment components have been mapped, evaluating the sources of funds that can enable the deployment is necessary. The following questions can be addressed:

- Does the municipality have the resources to invest in electromobility? **What assets can the municipality afford with its own resources? Do they require contributions from private stakeholders**, regardless of the form of remuneration?

- **Are there other sources of funds available for the implementation of an electromobility project** in addition to public resources or the granting to private stakeholders, such as resources from Climate Funds, fees charged for the use of public roads by app drivers or drivers in general, fees charged on rotating parking lots or other sources of funds established outside the operation of public transport?

It is worth noting that the source of the funds does not necessarily correspond to the attribution of responsibility for their execution. There are examples of important infrastructure projects in which the government had the necessary resources to implement a given investment but preferred to delegate the execution through concession contracts to the private sector. This is the case, for example, of the public-private partnership for implementing the Tamoios Highway or Metro Line 6, both in São Paulo; and the Salvador Metro, in the state of Bahia. In these projects, the governments of São Paulo and Bahia funded a significant part of the initial investments through PPPs, with capital transfers for the concessionaire to implement the necessary investments in the form and deadlines provided for in the notice [76].

Contrarily, in several infrastructure projects, the government took responsibility for implementing a specific asset and subsequently delegated its operation to the private sector, charging a grant for the right of exploitation. Known examples are the Western Stretch Ring Road in the state of São Paulo, and the ABD Corridor, in the Metropolitan Region of São Paulo.

As in the cases mentioned above, the criteria that guided the decision to separate the obligation to pay and the responsibility for the implementation aimed to increase project management efficiency, avoiding the segregation of responsibilities between multiple agents. However, in other cases, the intention to transfer risks from the public sector to the private sector was observed.

The efficiency of the implementation management model and the proper allocation of risks should guide the implementation of all components in a transition project for electromobility. As an example, the municipality may decide to bear the costs of implementing an improvement in the electricity grid using public resources or transfer the allocation of implementation of such improvement to the private sector (the power transmission company or the company responsible for the operation of electric vehicles), noting that in these cases the control and regulation of delegated services remain under the responsibility of the public authorities. In other words, it is essential to identify, among all the stakeholders involved in the implementation of electromobility projects, which are the most capable of assuming each of the responsibilities related to the implementation phase (purchase of vehicles, implementation of chargers, execution of civil support works and integration of all components), operation and maintenance of electromobility.

4.1.3 Third step

Once the sources of funds have been identified and the responsibilities for implementing the initial contributions set, the next step involves defining the origin of the resources that amortize and remunerate the investments made by private agents. Some of these features may come from charging users' tariffs. However, as evaluated in the previous chapters, electromobility projects should not significantly impact the rates for the use of the public transport system under penalty of making a "social policy inside out," which would oblige the most vulnerable people to bear the implementation of public policies that favor society.

Therefore, the fees paid by users should only be responsible for the portion of the amortization and remuneration of investments up to the limit of their maintenance, that is, by transferring the portion of resources initially destined to the remuneration of diesel vehicles for electric buses. After that, however, the value of rates may not be sufficient, which would require the adoption of complementary sources of funds.

Alternative sources of funds may include so-called "ancillary revenues" (i.e., the exploitation of assets in addition to their central function) to increase revenue. Classic examples of ancillary revenues are the rental of spaces for commercial activities in bus stops or subway stations and the rental of spaces for advertising and/or advertising in the body of electric vehicles. This last mechanism is strategic, for example, to associate the image of the sponsoring company with an environmentally correct and socially inclusive mode of transport, such as electric buses. Ancillary revenues differ from the revenues associated with The GdM because they are based on the use of the operational assets of the urban mobility system itself for the generation of complementary revenues. The revenues associated with Mobility Management as presented in section 3.2. Institutional and financial aspects, for example, come from the ownership or use of private cars, i.e., they are sources of funds external to the public transport system.

The sources of funds to remunerate and amortize the investments made by the private sector may include resources from the municipality itself. The contribution of resources can be made in the form of a “pecuniary return” in the case of public-private partnerships (based on Federal Law No. 11,079 of 2004) or a “user grant” through a common concession signed (based on Federal Law No. 8,987 of 1995). In this case, the system usage fee paid by users is separate from the compensation fee for the services provided by the concessionaire.

4.1.4 Step Four

Once the division of responsibilities between the multiple agents involved and the basis of each one’s remuneration model has been established, such definitions may gain materiality in a set of legal instruments. These instruments involve from the preparation of one or more concession contracts to the definition of guarantees, insurance, and others. The provision of services shapes the contractual, legal, and commercial relations between the parties, distributing and discriminating the responsibilities of each and aligning their interests.

4.2 BUSINESS MODEL ANALYSIS FOR ELECTRIC BUSES

Public transport concession contracts generally establish the supervision and management of services as the assignment of municipalities and planning and operation as a role of private initiative. Depending on the principles in the regulatory standards, contracts may include very restrictive clauses that discourage investment in more daring or high-risk innovation projects.

In cases of greater rigidity, low flexibility, and lack of cooperation between the parties reduce opportunities to expand risk sharing and innovations that optimize and modernize the service, constituting one of the main obstacles to introducing electric buses as technological innovation [77].

Business models for electric buses are broadly equivalent to the most popular models of contracting public services. On the one hand, those whose delegated object involves planning the implementation, programming, and management of the operation starting "from scratch," known as greenfield projects, shown in Table 9. On the other hand, there are hiring models where the assets used in the concession have already been deployed by the Government or previous concessionaires, called brownfield projects. Brownfield projects may provide for the renewal or modernization of previously existing assets throughout the contracting period, as exemplified in Table 10. Each of these business models seeks to meet a specific public policy objective, from which we seek to define the space of private performance and the form of interaction between private initiative and public authority. In the case of the transition to Electromobility, there are no previously defined formulas or models that are necessarily superior or preferable to the others. Each of these model alternatives can be adapted to different forms of private sector participation in the implementation, management, operation, and maintenance of public transport systems that use the modality of electric vehicles.

The following tables characterize some of the models applied in the infrastructure sector that can be used as a reference to define the transition to electromobility. This characterization presents the main functions performed by each agent, public and private, delimiting their responsibilities. Specific examples are presented below, and the main relevant points of the regulatory standard are indicated. The transition models for electromobility, developed in sections 4.2.1 to 4.2.4, start from the broader models in the following tables.

Table 9 – Procurement arrangements for unimplemented public services (greenfield systems)

Modality	Features	National and international examples	Regulatory standards
Availability contract	Private investor builds the system and transfers the transaction to the granting power. Public agents may delegate the operation to specialized agents or take over the operation through a public company. Part of the revenue from the service administration remunerates the private investor. The remuneration is for the lease of the asset to the public during the contract term or for payments linked to the transfer of ownership if this occurs immediately after completing the works.	In Brazil, the main availability contracts were signed in the sanitation sector. The São Paulo State Basic Sanitation Company (Sabesp), responsible for water supply and sewage treatment in the state, has made numerous bids for the construction and maintenance of water and sewage treatment plants. In the transport sector, the most common experiences are international; for example, in England, with airports and basic infrastructure for public transport systems.	Technical framework for the supply contract, considering the requirements necessary later for the provision of services. The technical framework may be objective, precisely defining what should be done; when the contracted party proposes the best technical solution for the infrastructure to be implemented.

Modality	Features	National and international examples	Regulatory standards
Common or sponsored grant with asset reversal	Classic concession model in the area of rail transport. The concessionaire receives a basic project and is in charge of the system's implementation, operation, and maintenance for a defined period. The ownership of the operating assets is the granting power, but the concessionaire retains possession of them and can depreciate the investments made according to the temporal distribution of demand. At the end of the concession period, the concessionaire reverts the assets to the granting power without charge.	National Examples: - Line 4 of the São Paulo Subway; - Line 6 of the São Paulo Subway; - Lines 5 and 17 of the São Paulo Subway; - Lines 1 and 2 of the Salvador Subway.	The standardization of projects emphasizes the quality of the service offered to the user and the quality of the assets implemented. As assets return to the government at the end of the contract, there is stricter compliance with the quality standards in the deployment and maintenance conditions.

Modality	Features	National and international examples	Regulatory standards
Common concession or traditional transport permit	Standard in motorized municipal urban transport projects throughout Brazil. The concessionaire makes the investments, operates the services following the contractual standard, and maintains ownership of the assets indefinitely, including at the end of the contract. In the pattern of existing contracts, there is no reversal of assets in favor of the granting power at the contractual termination, so no concession applies.	Municipal public transport systems in São Paulo, Rio de Janeiro, Brasília, Campinas, and several other Brazilian municipalities. This model is used in metropolitan regions of São Paulo, Recife, Fortaleza, and other parts of the country.	Different normative models. The most common provides for a higher level of planning and programming by the granting power, directly affecting the responsibility matrix of the parties. One example is the bidding process for the São Paulo Metropolitan Transport System conducted by EMTU-SP. In this case, the full extent of Operational Services Orders was stipulated by EMTU, which is the only management body to have the prerogative of altering the delegated object. On the other hand, the bidding of the public-private partnership of the Baixada Santista Metropolitan Transport System, also conducted by EMTU, establishes the principle that the Concessionaire company would have the prerogative to adjust the supply in the scenario of demand variations. Generally, standardization focuses on service quality, observing indicators such as maximum occupancy and interval between departures at or outside peak hours, among others. In addition, the standardization concerning the quality of investments is reflected in the type of vehicle used, at the maximum age, and in related themes.

Source: Own elaboration.

Table 10 – Modalities of contracting public services already implemented (brownfield)

Modality	Features	National and international examples	Regulatory standards
Concession of operation of public assets	Concession model usually applied to newly built projects, in which the granting power develops the infrastructure and hires the operation. It differs from outsourcing due to the risk of demand assumed by the private stakeholder, in addition to other risks of an operational nature.	Common in road concessions implemented by the government, which transfers the operation to the private sector. In the transport sector, it is common to delegate urban terminals to the private sector, but still experimental in projects involving the movement of passengers.	Legal framework for the operation[1]. New investments during the concession are negotiable but are generally the responsibility of the granting power.

1 The legal framework of operation is composed of a set of normative instruments, whether they take a form of laws, decrees, resolutions, and deliberations, or take the form of annexes of a contract, which stablishes a set of requirements that the private sector must meet when assuming the prerogative of providing an essential public service. Usually, the broader framework has transversality among several sectors, such as constitutional principles, or other sectors, such as laws which regulates the provision of certain public services to private sector. The Technical Contractual Framework complements the broader standard with specific aspects of the project to which the Concession Agreement refers. Typical examples are the maximum age that can be admitted for the operation; the maximum interval between the departures of a certain public transport route; the maximum occupancy level of the vehicles during a certain period.

Modality	Features	National and international examples	Regulatory standards
Concession for the renewal and operation of public assets	A model widely used to improve existing systems in which the public assets used in the provision of services are in a state of degradation. The concessionaire assumes the operation and is responsible for continuous improvements throughout the operating period.	- Supervias in Rio de Janeiro - CPTM Lines 8 and 9 in São Paulo	Strict regulation of the standard of services, but any technical framework is established according to the possibilities of improvements and investments verified throughout the concession. New investments during the concession are negotiable, and usually involve the granting power. It requires a robust regulatory agency.

Source: Own elaboration.

The choice of the type of public procurement depends on the objectives intended to be achieved, the availability of public resources, and the existence of a structure in the public administration appropriate to the exercise of operation functions, management, regulation, and supervision of services, among others. Considering all these elements makes it possible to outline and detail which business model is most appropriate for each case.

Contracts often involve the deployment and operation of assets by the private sector, i.e., a combination of the focus on the contract. These contracts usually form a common concession (Federal Law n° 8,987/95) or public-private partnerships

(Federal Law nº 11,079/04). These contracts emphasize the importance of extensively evaluating the following elements:

- Adequate allocation of risks: contracts should describe in their body in specific technical annexes all full risks that may occur during the implementation and operation phases, the possible impacts of their materialization, and the allocation of these risks according to the identification of the agent who is best prepared to receive it. Full risks should not be allocated to private initiatives but shared in a balanced way between public and private agents;

- Performance indicators: should adequately reflect the standard of services that are intended to be provided to the public service, establishing bonus mechanisms for overcoming it or sanction for not reaching it;

- The payment system: clearly identify whether rate or based on public resources (subsidies, contributions, and payment by the public sector);

- The economic-financial balance system defines which events are the right of the parties to recompose the economic-financial balance, the methodology for calculating the imbalance, and the variables that can be used to recompose the contractual balance.

These key elements of the contracts signed between the Government and the private sector should be addressed to create a set of positive incentives for the project. In the context of operation by the private sector, Table 11 presents the most common types of concession applicable to electromobility projects.

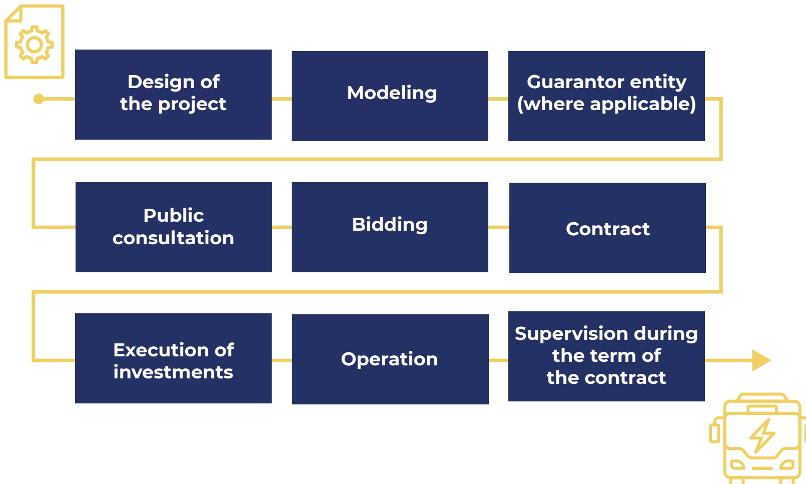
Table 11 – Possible concession types for electromobility projects

Type of concession	Common	Sponsored	Administrative
Concept	It is the delegation of public services, public works, and public service permits, whose remuneration comes from the fee paid by the user of the services covered by Federal Law n° 8,987/95	It is the delegation of public services or public works that deals with Federal Law n° 11,079/04 in cases where it involves, in addition to the rate charged to users, a cash return from the public partner to the private partner.	Service contract in which the public administration is a direct or indirect user, even if it involves the execution of work or the supply of goods.
Remuneration	By tariff collected.	Payment paid by the public administration + rate paid by the user	Payment by the public administration.
End-user relationship	The concessionaire company is directly related to the end user and charges the tariff.	The private partner is directly related to the end user and charges the tariff.	The private partner has no direct relationship with the end user, the public administration.
Goals	Defined in contract.		
Regulation and supervision	Defined in the contract and may include mechanisms of performance indicators.		

Source: Own elaboration.

The steps for hiring one of the modalities and for the delegation of services follow the synthetic path illustrated in Figure 19.

Figure 19 – Delegation process of public services



Source: Own elaboration.

To formulate and evaluate the most appropriate business modality for public transport projects (involving all or part of electric bus components), cities may consider the alternatives described below as a reference. As examples are analyzed in Brazilian and Latin American cities, it is important to note that there are adaptations of these four alternatives presented.

4.2.1 Alternative 1

This alternative refers to implementing and operating electric buses under full public responsibility. Implementing electric fleets through public administration can be presented as an alternative to initiating the transition process to electromobility. In later stages, the government could resume conventional models with a higher level of sharing of responsibilities with private initiatives.

The first alternative is the constitution of a public company dedicated to operating and implementing an electric fleet system. The public company would also articulate the organizations responsible for the operation and implementation of associated infrastructures.

This alternative was adopted in the past in Rio de Janeiro in São Paulo for conventional bus and metrorail systems, for example. Companhia do Metropolitano de São Paulo and CPTM were founded to implement, operate and maintain the São Paulo metrorail system. São Paulo's own bus system has already been operated by a public company, the Companhia Municipal de Transporte Coletivo (CMTC). In Rio de Janeiro, Flumitrens was created to explore the rail transport system, while Metrô Rio explored lines 1 and 2 of the subway system. Subsequently, a relevant part of these systems was delegated to the private sector. In São Paulo, lines 4, 5, 6, 17, and 18 of the São Paulo Metro were the object of delegation, in addition to CTPM lines 8 and 9. In Rio de Janeiro, Flumitrens' operation was delegated to the current Supervia and Metrô Rio, which a private concessionaire also manages. São Paulo's tire transport system was delegated to the private sector in the early 1990s. Regarding the adoption of electric buses, there are still no examples at scale.

4.2.2 Alternative 2

This alternative refers to implementing and operating electric buses under full private responsibility. **This alternative is the most common in public transport service contracts.** It is guided by the full delegation of the operation to the private sector. The full delegation implies that all pre-operational activities of the electric fleet, from the preparation of executive projects (through the obtaining of resources, the means of implementation, and integration of investments) to the beginning of the effective operation and commercial operation of the services would be attributed to the private sector.

Once the acquisition or leasing of electric buses and their components is completed, systems integration and operation preparation, the operator becomes fully responsible for managing and commercially exploiting the system — including the maintenance and conservation of assets and the provision of services related to urban mobility, among other responsibilities.

One of the main risks of this alternative is associated with investment costs, demand fluctuations, effective operating costs, and macroeconomic fluctuations. However, the largest share of the risks is attributed to the private sector, which is better prepared to take them by having the appropriate management and operation mechanisms.

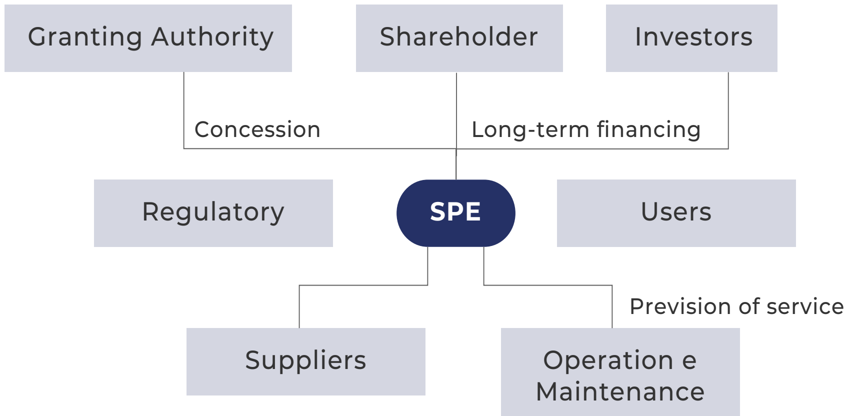
As for the ownership of the assets, all elements are treated as linked assets, affected by the provision of a particular essential public service. At the end of the concession, all assets remain under the private sector's property, except those mandatorily reverted to the granting authority.

By adopting this alternative, cities would be able to enjoy excellent financial benefits, thanks to the strong asymmetry in the allocation of responsibilities and risks between the granting power and the private sector, transferring to this, a large part of the duties of investing, providing an adequate public service, according to the performance parameters established in the contract, to keep the assets in appropriate conditions. Furthermore, it is observed that at the end of the contract, the Public Authority receives in a non-costly transfer the previously established part of the operational assets used in services' provision.

For the private sector, the necessary consideration for the assumption of responsibilities is the need to remunerate the capital used in the enterprise adequately. Figure 20 presents in a synthetic way which agents are directly involved in the organization of this business model and which possible formal or informal contractual relationships exist. In summary, the table presents the (i) Granting Power which is the federated entity responsible for the provision of the service and which can provide it directly or delegate it to the individual under Article 175 CF; (ii) The winner of the bid organizes and form a Special Purpose Company (SPE) whose shareholders are those who have submitted a proposal; This SPE may take out loans with investors (Banks) and guarantee the service itself, and is responsible for providing the service and relating to suppliers and employees; (iii) The Regulator establishes the rules and oversees the Concession Agreement.

In this figure, it is observed that there is only one contractual relationship signed, usually in one of the modalities of a concession contract (common or sponsored), delegating to the private sector the entire investment functions and provision of services to end users.

Figure 20 – Model of implementation and operation of electric buses under full private responsibility in a single contract



Source: Own elaboration. Note: LP - Long-term.

In electromobility projects that take this condition, the activities of acquisition, and implementation, the contracted company directly performs the integration of systems, operation, and maintenance. Some examples are found in the Federal District (DF), Santos (SP), Bauru (SP), Maringá (PR), and Campinas (SP). In part of the contracts signed in these cities, investments in the acquisition of electric vehicles and charging systems were already foreseen in the original financial equation. Therefore, based on the model, subsequent investments and increased operating costs represent the object of recomposition of the financial balance. It is worth noting that, in all these cases, electromobility is in the experimental phase. Thus, the operating companies are responsible for the costs of acquisition, operation, and maintenance of these systems, and the private sector is responsible for reviewing the initial economic-financial balance due to increased investment costs and decreased operating costs given the lower variable cost per kilometer traveled by electric buses compared to diesel vehicles.

Figure 21 – Battery-operated electric minibusses were already running in Santos in 2017 and, after the concession contract revision, returned to the streets in 2021

Credits: Alexsander Ferraz, A Tribuna (2017)

Cities such as Brasília, Maringá, and Santos are municipal references for implementing and operating electric buses under full private responsibility in a single contract, exemplifying how these processes can be implemented.

In the Federal District (DF), reviewing the contractual financial equation has already incorporated the acquisition of the electric bus fleet. However, it has not yet been adjusted to incorporate the effective long-term costs of fleet operation and the transition in scale and financial sustainability.

In Maringá (PR), the operation takes place on an experimental basis, with no indication that the concession contract is rebalanced to accommodate the introduction of this technology in the long term.

In Santos (SP), two electric battery minibusses were acquired by a concessionaire company without such investments affecting the calculation of the user's rates. In addition, the tariff also incorporates the operation of trólebus, an electric bus modality already in operation before bidding.

4.2.3 Alternative 3

This alternative refers to the shared responsibility for implementing and operating electric buses between public and private entities. **Cities that adopt this alternative may enable the adoption of electric buses through conventional bidding for vehicle acquisition and implementation of charging systems and eventual operational control**, governed by the terms of Federal Law No. 8,666/1993[2]. This contracting, conducted by the granting authority, takes place through the specifications of the assets to be incorporated into a second contract. These assets are considered "assets linked" to the delegation of the service.

The second contract of operation has as its subject the construction of garages, terminals, other collection systems, control, monitoring, management, and others. Besides the investments, it also implies the execution of the operation and maintenance of operational assets, including those provided under the first contract. At the end of the contract, in the thesis, all assets remain under the operating company's property except those linked to the concession initially made available by the granting authority.

As the goods linked to the service concession are reverted to the granting power once the contract ends, the contract's maintenance and operational rules during the reversal may be defined. The model follows, for example, the molds established for implementing Line 4 of the São Paulo Subway.

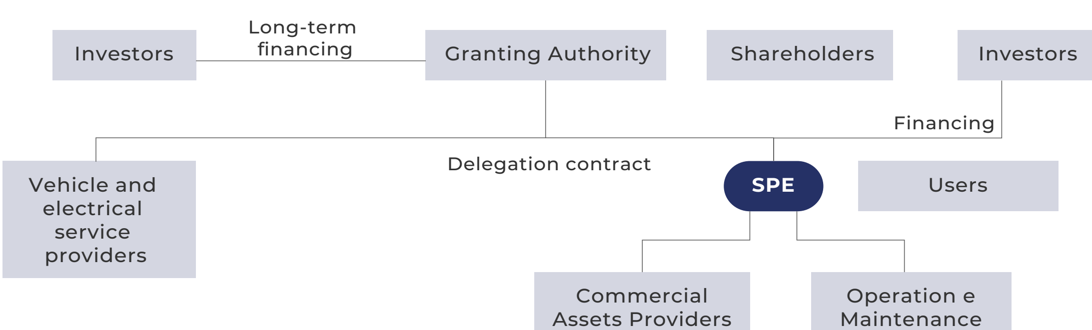
Figure 22 below presents a review of the position of the main stakeholders in a new contractual arrangement. First, it is observed that the Government may contract long-term financing to acquire electric vehicles and charging systems and conduct civil works for their implementation, transferring the use of these assets to the private sector in the middle of the contract of delegation of public services granted to

2 The new Bidding Law (Federal Law n° 14,133/2021) was published on April 1, 2021, while Law n° 8,666/1993 remains in effect until April 1, 2023.

the private initiative. As a result, the private sector operates these assets, providing services to the system's end users.

Figure 22 shows the stakeholders from two contractual relationships that occur in parallel. Contract 01: (i) Granting Power which is the federated entity responsible for the provision of the service and which may provide it directly or delegate it to the private sector under Article 175 of the Federal Constitution, as well as Federal Law nº 1,079/2004; (ii) The investor where the Granting Authority gets the loan to purchase or lobe the vehicles (iii) This relationship is established between Granting Power (contractor) and Suppliers of Vehicles and electrical systems and delivers them to the winner of the service delegation bid, with specific rules for such delivery and return. Contract 02: (i) Granting Power which is the federated entity responsible for the provision of the service and which may provide it directly or delegate it to the individual under Article 175 of the Federal Constitution; (ii) The winner of the bid organizes and form a Special Purpose Company (SPE) whose shareholders are those who have submitted a proposal; This SPE may take out loans with investors (Banks) and guarantee the service itself, and it is responsible for providing the service and relating to suppliers and employees; (iii) The Regulator establishes the rules and oversees the Concession Agreement.

Figure 22 – Model of responsibility for the implementation and operation of electric buses shared between public and private entities



Source: Own elaboration. Note: LP: Long term.

Figure 23 – São José dos Campos segregated, by contract, the acquisition of 12 articulated electric vehicles manufactured by BYD

Credit: Cláudio Vieira, Local government of São José dos Campos (2021).

This model was adopted by São José dos Campos's municipality in the state of São Paulo. The municipal management chose to segregate the acquisition of the assets of the operation in different contractual structures. The articulated electric vehicles operating in the so-called "Green Corridor" were purchased from the supplier BYD according to technical specifications disclosed by the Local government.

The acquisition included, among others, the guarantee of perfect functionality of the batteries for ten years and a wide set of manuals aimed at the necessary integration of vehicles to other contracts. The second contract was with the company Nansen, which has expertise in controlling electrical systems and is responsible for developing control and charging systems.

The city manages the interfaces between Nansen and BYD to determine technical parameters and compatibility between systems, among other aspects. Finally, all these assets are transferred through a concession contract to the operator of lot 1 of the Public Transport Service of São José dos Campos. The operator is responsible for the construction of garages and administrative infrastructure and the service operation and asset maintenance, including those transferred by the municipality.

It is worth noting that, in São José dos Campos, the implementation and management of technologies, including databases from electronic ticketing systems, should be contracted through a separate process — that is, the technology operator is different from that responsible for providing passenger transport services.

4.2.4 Alternative 4

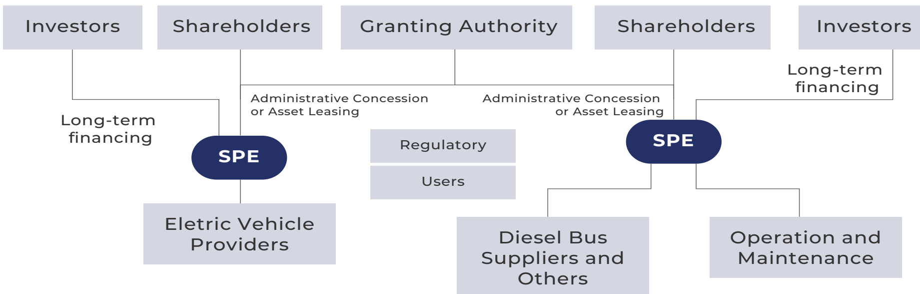
This alternative refers to implementing and operating electric buses under private responsibility in two separate contracts. This model segregates the activities of implementation and operation of electric vehicles in two separate contracts delegated by the Public Power to the private sector.

The first contract, aimed at implementation, defines the agent responsible for deploying vehicles and charging infrastructure, including civil works and systems, in a long-term contract. This contract may be conducted in the form of asset leasing if it involves only or predominantly the implementation of such assets. As the maintenance of the systems and eventually the maintenance of the vehicles themselves are incorporated into the contract, partially or completely, the arrangement would constitute an administrative public-private partnership (PPP) with long-term remuneration.

The second contract, regarding the operation, involves the construction of garages, terminals, other collection systems, control, monitoring, management, and others. It also implies, in addition to the realization of investments aimed at the provision of services not included in the first contract, the full execution of the operation and maintenance of operational assets, including those provided under the first contract. Furthermore, the responsibility must be established on the assets (buses) under its custody and use.

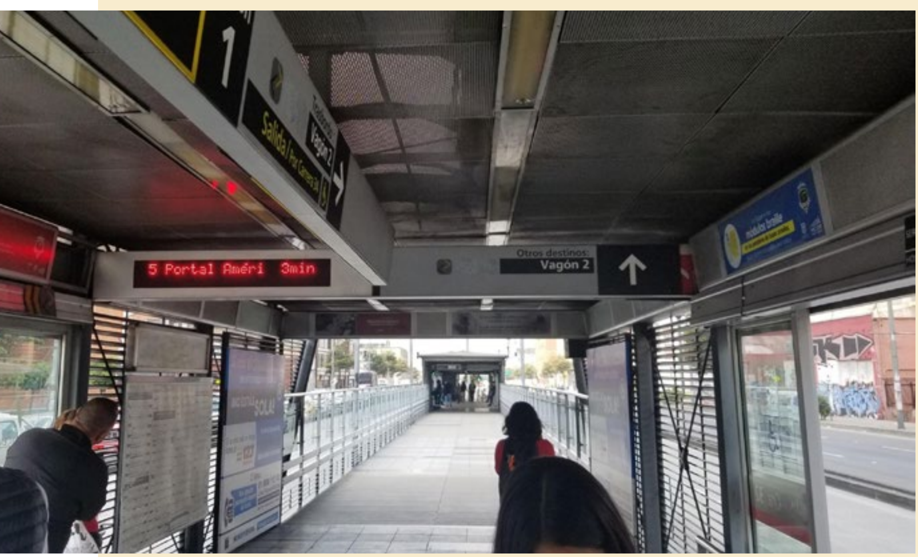
Figure 24 presents the stakeholders from two distinct contractual relationships. Contract 01: (i) Granting Power which is the federated entity responsible for the provision of the service and may provide it directly or delegate it to the private authority under Article 175 of The Federal Constitution, (ii) The winner of the bid organizes and forms a Special Purpose Entity (SPE) whose shareholders are those who have submitted a proposal. This SPE may take loans with investors (Banks) and guarantee the service itself and is responsible for acquiring or financing the assets (buses) and relating to the Concessionaire providing the Transport Service. Contract 02: (i) Granting Power is the federated entity responsible for providing the service and may provide it directly or delegate it to the individual under Article 175 CF. (ii) The bid winner organizes and forms a Special Purpose Entity (SPE) whose shareholders are those who have submitted a proposal. This SPE may take out loans with investors (Banks) and guarantee the service itself, and it is responsible for providing the service and relating to suppliers and employees. (iii) The Regulator establishes the rules and oversees the Concession Agreement. In this model, the Granting Authority segregates the contracts for the acquisition and/or lease and the transport service contract.

Figure 24 – model of implementation and operation of electric buses under private responsibility in two distinct contracts



Source: Own elaboration. Note: LP: Long term.

Figure 25 – Transmilenio passenger boarding and disembarking station, Bogotá, Colombia



Credit: Rodrigo Laboissiere, Logit (2019).

In 2019, the Colombian capital revised its concession contracts for its BRT (bus rapid transit) system, TransMilenio. One of the main innovations was to separate the provision services (Capex, capital investments, or acquisition costs) and operation (Opex, operating expenses, or operating costs) of the fleet into separate contracts and bidding processes [78].

Thanks to the new business model, stakeholders with greater financial capacity began to join forces with local operators in the concession of the service, conferring viability and stability. For example, Volvo's partnership with two private operators provided 300 hybrid electric buses for the TransMilenio. The cost of the buses was separated from the batteries: private operators bought the buses from Volvo, and the city signed a leasing contract for the batteries [79].

In 2020, a statement issued by Sofia Zarama Valenzuela, head of planning at TransMilenio (Bogotá, Colombia), told WRI the main advantages observed from the change [80]:

- Continuity of service: as the city can maintain the provision contract, ensures the appropriate transition between current and future operators at the end of contracts;
- Flexibility: in the face of contingencies with any operator, TransMilenio, as a manager, can pass the fleet to another operator without the need to renegotiate contracts;
- Bankability: the division of operating risks and provision helps to attract investments for fleet renewal; and
- Efficiency: The division allowed TransMilenio to adopt a cleaner fleet without increasing the tariff.

Figure 26 – innovation in business model has made Chile a reference in electromobility worldwide

Credit: World Bank (2019).

In 2017, the Chilean capital faced problems renewing the transantiago system fleet (now RED). The buses were close to reaching the maximum age allowed to continue running. Therefore, a bid was planned to re-fleet, but it was considered deserted due to a lack of interested companies. Thus, Santiago took advantage of the emergency to review its business model to make it more attractive. As a result, two bidding processes were established to acquire 2,000 buses (including electric buses).

One bid was directed to the vehicles' supply and another to the fleet's operation. According to information from the Public Transport Board of Santiago, the city considered that this change would contribute to expanding the operational continuity of the fleet, increasing competitiveness, improving standard quality, promoting more sustainable technologies, and reducing system costs [81].

Inspired by Chinese cities, Santiago's new model sought to include other players in governance, creating a consortium between vehicle and chassis manufacturers and financial entities. In this agreement, the financial sector would acquire the vehicle from the manufacturer and rent it (via a leasing contract) to the city or operator.

Santiago also successfully incorporated incentives and obligations into contracts, specifying the technology used and ensuring that a percentage of the fleet was low- or zero-emission vehicles. As a result, the city is estimated to invest US$800 million a year with its own resources [82].

4.3 NATIONAL CONTEXT AND OPPORTUNITIES FOUND FOR BUSINESS MODELS

When evaluating the applicability of alternative business models aimed at transitioning to electromobility, it is important to understand how the national context defines limits or favors a given modeling profile. In addition, understanding the paths of lower resistance to the implementation of electromobility is a key element for the success of its initial stage and for ensuring the long-term sustainability of technology, generating maximum social benefit.

As for the first business alternative (item 4.2.1), based on planning, implementation, and operation by a public sector, it is essential to note that, in most Brazilian municipalities, no public sector effectively operates public transport services. Therefore, the creation of a specific entity for this purpose would imply a significant number of institutional measures, such as:

- Formal creation of the company, with statute and regulation, among others, and approval of the City Council;
- Definition of a plan of positions, salaries, and realization of a selection process for the hiring of employees and;
- Organization of internal procedures for contracting assets, operational planning, and the operation itself.

Due to the institutional processes in force in Brazil, adopting a transition model for electromobility that implies the creation of a public company can be an excessively long and expensive process. Moreover, to the extent that such organizational models have more rigidity in their internal organization, an eventual transition to operation by private agents to bring more innovation to the system could generate additional costs for the municipal public.

Opportunity 1: public operating companies. Several Brazilian municipalities have, in their indirect administrative structure, companies that conduct the transport of passengers. These companies generally enjoy consolidated operational expertise and an administrative framework that organizes transport services. Therefore, they can play simply and effectively the role of catalysts in the transition to electromobility by replacing the operation of diesel vehicles with electric vehicles. In addition, this would create a database on productivity and costs that could be relevant for future private hires.

Figure 27 – BYD electric bus purchased by Unicamp for passenger transport at its campus in Campinas (SP)

Credit: Antonio Scarpinetti, CPFL (2020).

The electric buses that make up the internal circular fleet of the Transport Services Directorate (Unitransp) of the State University of Campinas (Unicamp) are examples, on a local scale, of how the operation of electric vehicles can occur under full public responsibility. Since September 2020, vehicles have been transporting passengers on campus. The Living Laboratory of Electric Mobility conducts the operation, part of the Sustainable Campus project, financed with resources from the holding company CPFL Energia, which distributes, generates, and markets electricity [83].

The project had a total cost of R$ 3.4 million and received contributions from the Office of Special Projects, linked to the General Coordination of the University. The initiative serves as a basis for observing the costs of implementation, operation, and evaluation of the efficiency of electric buses. In addition, it aligns with the management principles of a cutting-edge university that invests in prestigious and reputable intangible assets. Furthermore, the Sustainable Campus Project has other fronts, such as replacing old equipment with new ones, which consume less electricity; managing energy consumption of buildings incorporating internet of things (IoT) resources, and installing photovoltaic power-producing units at various points on campus.

Opportunity 2: public service managing agent. Cities that wish to start the transition to electromobility through a public operation, but do not have a Municipal Public Company, a member of indirect administration with administrative and financial autonomy dedicated to the Operation of Public Transport, may adopt an experimental operation through the management of contractual links carried out by one of its Secretariats such as the Secretariat of Works or Public Transport.

The chosen Secretariat is responsible for the contracting and integration of four sets of contracts: (i) preparation of studies and projects to adapt the infrastructure to electromobility; (ii) contracts for the adequacy of infrastructure to electromobility; (iii) acquisition of vehicles and batteries to start operation; and (iv) hiring a company to provide skilled labor for the provision of public services. Figure 28 below summarizes the process.

Figure 28 – Sets of contracts under the responsibility of the public managing agent

Public Management Agent

Contract 1: Specialized Designer Cpmpany	Contract 2: Equipment and system supplier(s)	Contract 3: Vehicle and component suppliers	Contract 4: Labor suppliers
Definition of routes Identification of charging points Identification of rcharging times Network diagnostics andication of required improvements	Implementation of identified improvements regarding infrastructure and its recharging points	Supply of vehicles, charging infrastructures and batteries for operation	Supply of tchnical personnel, materials, and others for the vehicles' operation

Source: Own elaboration.

As cities feel safer adopting electromobility, the organizational structure can quickly demobilize. In this sense, the acquired assets are transferred to the private sector as public goods "affected" by a certain concession contract to be tendered. This was the case observed during the decades of 1980 to 2000 in which the so-called "privatizations" of public passenger transport companies occurred. Examples are the Companhia Municipal de Transporte Coletivo of the Municipality of São Paulo - CMTC and the Urban Transport Company of the Municipality of Recife, CTU. In both cases, bids for granting the right to provide the public service of public transport of passengers were combined with the disposal of the physical assets previously used by the public company to provide these services.

Applications of these models are also common in subway transport or suburban trains, where public assets previously deployed for a given service are later linked to the concession for the provision of public services by a private agent. For example, in the 1990s, this model was applied to the concession of the suburban train system of the Metropolitan Region of Rio de Janeiro when Flumitrens was granted and to the concession of its subway system. In recent years, in 2020, Companhia Paulista de Trens Metropolitanos yielded the use of operational assets linked to the provision of public services to conduct the Concession for Operation, Maintenance, and Commercial Operation of Lines 8 and 9 of that system.

Opportunity 3: public service concession

The induction of electromobility through contracts for the concession of public services based on Federal Law nº 8,987/95 when granted in the form of common concession or on Federal Law nº 11,079/04 when granted in the form of sponsored or administrative concession has become the business model most adopted by cities. Recent examples include the Santos and Bauru municipalities in São Paulo, the Municipality of Londrina in the State of Paraná, and the Federal District. However, to be effective, the process depends on the stage in which private relations with the municipality are located, as shown in Table 12.

Table 12 – Alternatives of action according to the contractual stage of the relations between the municipality and the operating companies

Bidding for new contracts	Attribution of risks to the public stakeholder	Calculation of system costs based on diesel technology or costs estimated by the government. Periodic reviews of the financial equation of the contract as the cost and productivity variables are consolidated.
	Attribution of risks to the private stakeholder	Calculation of costs and compensation of the system based on costs and productivity estimated by the government, reviewed by the private stakeholder in the bidding process. Cost or productivity variations do not ensure the review of the contract equation.

Inclusion of electro-mobility in existing contracts	Remaining contractual term longer than the life of the vehicle	Addition of the concession contract to include costs related to studies, projects, implementation of additional infra-structure in charge of the private stakeholder, acquisition of vehicles, and operation through economic and financial rebalancing of the concession contract. The assets invested may or may not be reversed without the need for indemni-fication of assets at the end of the contract.
	Remaining contractual term lower than the life of the vehicle	Addition of the concession contract to include costs equiv-alent to the preceding item by an economic and financial rebalancing of the concession contract. The assets invested may or may not be reversed, and investments not amor-tized at the end of the contract must be indemnified.

Source: Own elaboration.

For concession or permit contracts in force, it is worth noting that the process of addition and re-establishment of the contractual economic-financial balance needs to be conducted through negotiation between the parties. The unilateral imposition of investments by the municipality is little recommended, as it generates undesirable repercussions on all other spheres of the contract. In such a negotiation process, the parties should understand what each can gain and/or lose with the transition to electromobility.

The parties should carefully plan and study the processes of reviewing the contractual balance in managing public passenger transport services. The contours brought by the legislation are added to the monitoring of control bodies so that the process of review of the contractual balance should be transparent and with reliable information.

On the other hand, several components of possible marginal gains can act as catalysts for the profitability of a business. Typical examples are the resale of used vehicles or the negotiation of large volumes of fuels, which may represent an additional gain to the operation itself.

These elements should not be motivated as enablers of urban mobility projects since the direct consequence of the resale of diesel vehicles to smaller municipalities and the intensive use of combustion vehicles is worsening the quality of the air, so the impossibility of carrying forward such marginal gains is something that should be reflected in the new financial models.

One opportunity is to establish in this resale market more efficient technologies under the regulatory standards on the emission of pollutants for diesel engines (i.e., Euro VI system, scheduled to enter into force in 2022 in Brazil in phase 8 of the Programa de Controle de Emissões Veiculares [Proconve], CONAMA [National Council for the Environment]).

In contrast to the losses of marginal opportunities, the operating companies enjoy relevant expertise and the technical attestation necessary to participate in future bidding procedures in several municipalities where the transition is planned. Thus, the parties should weigh their gains and losses in the process to create a positive sum result for both sides.

The third business model evaluated (item 4.2.3), in which the government is responsible for acquiring vehicles, infrastructure, and batteries and conning these assets to a private operator in the form of a public good, also presents challenges and opportunities. One of the challenges municipalities face is the existence of a qualified technical staff capable of developing and integrating the interfaces of all responsibilities assigned to it.

This qualified technical staff may represent a cost to the municipality, which should be evidenced in the weighting of the project's benefits. On the other hand, by doing so, the municipality reduces the share of investments made by the private operator, proportionally reducing the costs of amortization and capital remuneration that should be considered in the future. Thus, in the long run, there is an important nominal gain for the system since the cost of direct financing of the acquisition of electric vehicles by the Government is usually lower than the cost of remuneration of private capital established in concession contracts.

Companies look at the themes described above on the private sector side, i.e., the loss of marginal earnings opportunities. However, in an even more relevant way, they need to pay attention to the reduction of their scope of services since the supply of vehicles and infrastructure will no longer make up their contractual object. Such suppression of scope should force companies to specialize more and more in managing the operation of services and less in their administrative aspects. The result may be an induction into the change of profile of operating companies. Such a change may be resisted at first, but it might be potentially beneficial to all parties in the long run, as new specializations result in more efficient and less costly operations for the city.

Finally, the fourth model (item 4.2.4) segregates the implementation and operation of the system into two distinct contractual structures, materializing the separation of financial and operational functions of the operation of public passenger transport. This provides an opportunity for new stakeholders to be incorporated into the "urban mobility ecosystem," such as investment funds, energy distribution companies, and entities of a similar nature, as observed in the cases of Bogotá (Colombia) and Santiago (Chile). These stakeholders would not usually participate in a classical bidding procedure as they tend not to have relevant operational expertise. On the other hand, the transparent segregation of attributions enables its entry into the sector, creating a business dynamic and inducing each stakeholder to greater technical specialization.

A key point to be considered is access to green funding lines, such as the Climate Fund Lines – Efficient Machinery and Equipment or the Climate Fund – Urban Mobility. Financial agents generally resist financing private companies with hybrid operations, that is, operating electric and diesel vehicles. Therefore, the contractual segregation of the purchase and financing of electric vehicles offers access to more competitive lines of credit for acquiring such vehicles.

4.4 CRITERIA FOR SELECTING BUSINESS MODELS

The criteria for selecting the business model for municipalities in transition to electromobility should be carefully analyzed, considering the possibility that such a model could become a public policy aimed at developing municipal electromobility. The main criteria to be observed would be:

- Relevance (or not) of the entity responsible for the implementation and operation (public or private) to the financial variables of the project, i.e., demand, tariff revenue, investments, and operating costs;
- Minimization of the fiscal effort of the public sector that is, identification of a model that generates the greatest value for the public resources available for the implementation of the project;
- Minimization of the risk of integration between the operational technology of vehicles, charging systems, operation, and maintenance of services. The integration between the multiple interfaces of the project should occur perfectly in the implementation phase and the maintenance phase of the enterprise;
- Regulatory complexity associated with the management of multiple contracts, such as supply, operation, and maintenance, by the granting power; and
- Minimization of the risks incurred by the granting power in developing the proposed model.

According to the criteria adopted, the financial results depend on the profile of the stakeholder responsible for conducting the enterprise. As a rule, public companies must comply with the statutes of public service, which can considerably increase operating costs. As for the model of the acquisition of goods and services, the government is shaped by several principles of administrative law, many of them transcribed in Federal Law No. 8,666 of 1993[3]. These principles can make the acquisition processes of assets, equipment, services, and others more costly than those conducted more freely by the private sector.

Based on these criteria, Table 13 compares the different models to guide cities in understanding their applicability and level of risk.

Table 13 – Business models: nomenclatures, applicability, and level of risk

Model	Examples	Functioning	Advantages	Risks
Public carried out entirely by the government without delegation to the private sector	Universidade de Campinas Trolleybuses in São Paulo (CMTC)	Structuring of a public company responsible for planning, scheduling, acquisition of assets, operation, and maintenance.	The government has a high degree of direct control over the use of the resources employed. Possible advantages in the rate structure of the energy supply may contribute to the reduction of operating costs.	Increase in investment and operation costs due to the rigidity of public procurement, both concerning personnel (status of public employees) and equipment, parts, and other productive inputs. Need for immediate disbursements by the granting authority.

3 New bidding law enacted through Federal Law n° 14,133/2021, was published on April 1, 2021. However, Federal Law n° 8,666/1993 remains in effect until April 1, 2023.

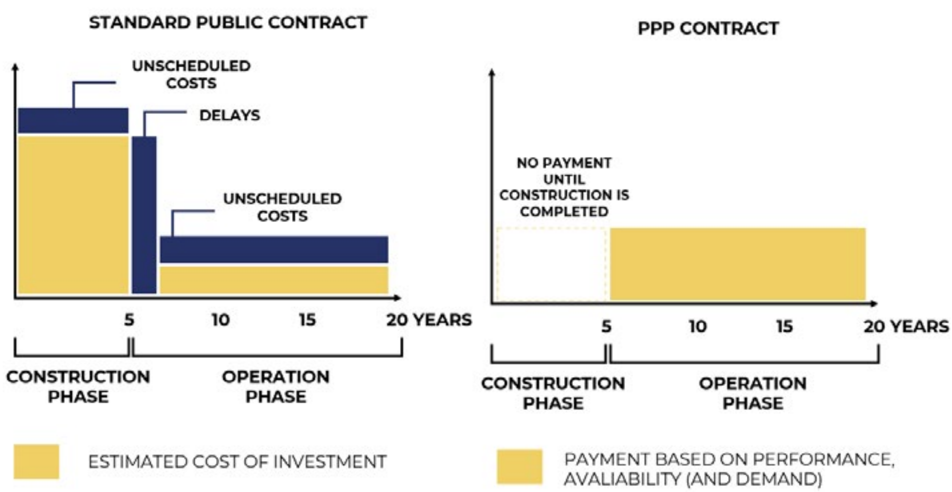
Model	Examples	Functioning	Advantages	Risks
Global Concession	Concession contracts in force in São Paulo, Brasília, Curitiba, and other municipalities or metropolitan regions migrating to electromobility	Contracting a single concession with the object of deploying, operating, and maintaining the public transport system with electric vehicles. Private remuneration combines resources received throughout the implementation phase (public contributions) with funds received in the operation phase (tariff remuneration and/or cash return).	The government disburses resources according to verified contractual frameworks (e.g., vehicle acquisition, systems, and installation). The risks of over-costs of implementation, interface management, and related topics are attributed to the private sector, limiting the exposure of public resources within the project.	Public governance is limited to contractual rules. The government does not define which assets are acquired based on the contributions. The concessionaire assumes all the risks involved in providing the service. Therefore, there is the possibility that the private cost of financing the acquisition of vehicles is higher than the public cost, affecting the Project's TCO.

Model	Examples	Functioning	Advantages	Risks
Public acquisition and private operation	Municipality of São José dos Campos	The granting authority acquires vehicles and/or charging systems and grants them to the private operator in the form of goods linked to the concession. The private operator is responsible for its operation, maintenance, and eventual renewal throughout the contractual term.	The government maintains direct control over the use of the resources employed.	Need for immediate availability of public resources. The management of interfaces between supply and conditions of use can burden public resources. For example, the case of Line 4 of the São Paulo subway indicates that failures in a contract may result in high penalties for the government.
Long-term parallel contracts	Bogotá, Colombia, in the renovation for transmilenio electromobility, and Santiago, Chile, in its introduction to electromobility	The granting authority carries out long-term contracts based on the BLT model [construction, lease, and transfer] in which the private investor invests in vehicles and systems and rents them to the government (or possibly to the second private operator, contracted to make investments in diesel vehicles, garages and other operational infrastructure), in addition to operating and maintaining all systems.	Reduces the need for immediate availability of public resources for investments, with a view to financing being dedicated to private PES.	Management of interfaces between contracts. The case of The London Underground, for example, under the management of LUL (London Underground Limited), highlighted the risks of the model and the difficulties of managing complex contract interfaces, which ultimately fall on the granting power.

Source: Own elaboration.

The synthesis of the proposed criteria establishes what is described as value for money (VfM) analysis, explained in Figure 29. This analytical aspect helps establish the best model for delegating contracts to the public in financial terms. In addition, it explores the models with the lowest levels of fiscal effort, risks, and regulatory complexity for the cities involved in the enterprise.

Figure 29 – Conventional view of VfM



Source: Own elaboration.

Despite the various studies and bidding processes in progress, no database available until 2021 would allow comparing the unit values effectively disbursed by cities for direct acquisition with the global costs contracted through PPP contracts, common concession, or asset leasing.

Unscheduled costs, delays, and risks assumed by cities can generate overcosts of 25% to 40% compared to the budget foreseen in basic projects. These risks are minimized in a global concession agreement. On the other hand, it should be considered that the cost of private financing is, in several cases, higher than the cost of public funding. There is even a significant risk that operators are not able to provide guarantees to investors for the purchase of new electric vehicles.

As the second important point of reflection, a concession contract providing for the division of risks between cities and private initiatives will, in return, need the granting power to define important guarantees of contractual compliance.

5.

MEANS OF IMPLEMENTING PROJECTS

This chapter indicates the most appropriate means and technical tools necessary for cities to structure electromobility projects considering the specificity of each reality and based on the initial planning guidelines and business models. The main aspects addressed are:

- Existing mechanisms and instruments for the provision of public services (and what opportunities they can provide for the transition project to be adhered to);
- Instruments to encourage industry and technical capacity;
- Governance and capacity to supply electricity to power the bus system;
- State of the existing transport system and infrastructure, with potential expansion capacity and resilience;
- Other financial attributes include access to financing, subsidies, and debt capacity.

The additional purpose of this item is to help municipalities identify and solve the main problems that may impose obstacles to implementing projects and proposals for electromobility in public transport systems. Finally, ways to identify and choose the most viable scope and horizon for electrification are examined, considering the above items and issues of social, economic, and financial sustainability.

5.1 POLICY-REGULATORY INSTRUMENTS FOR IMPLEMENTATION

Cities have been using different political instruments, with a variable degree of function and effectiveness, in their decisions regarding adopting electric buses. These instruments can have regulatory aspects, for example, when the government establishes goals and standards, monitors air quality, standardizes activities, and applies fines, penalties, and compensation criteria. The Climate Law (no. 16,802, of January 17, 2018) of São Paulo is the most significant case. There are also master plans and/or specific urban mobility plans published by each municipality. Service concession contracts can also be regulatory instruments: they determine technical and operational questions about how the fleet will be made available and how the service will be provided and highlight economic and financial issues about how companies will be remunerated and penalized if there is non-compliance with established contractual obligations.

Figure 30 – The trolleybus helps the state capital to meet the goals set out in the 2018 Climate Law

Credit: Folha de São Paulo (2021).

In 2018, a new wording given to Article 50 of Law No. 14,933/2009 (which instituted the Climate Law in the city of São Paulo) offered more precise guidelines on the use of energy sources that are less polluting and that generate less greenhouse effect, in the municipal fleet of urban public transport. The change resulted in Law No. 16,802 of January 2018, today a crucial guideline to guide São Paulo´s transition to decarbonization. The measures determine that, by 2038, public transport by bus may eliminate its carbon dioxide (CO_2) emissions and reduces by at least 95% its emissions of particulate matter (PM) and nitrogen oxides (NO_x) compared to 2016.

In September 2019, São Paulo entered into new contracts for public transport by bus operation, predicting changes per the emission reduction targets proposed by the Climate Law. Advances towards electrification are happening as the fleet of diesel vehicles also modernizes. Of the 350 electric buses in the country, 218 are in the capital of São Paulo, and 96 are in its metropolitan region.

To ensure replacement, the Steering Committee of the Fleet Replacement with Cleaner Alternatives Monitoring (Comfrota) was created. The program has played a significant role in monitoring the replacement of diesel vehicles based on the current standards of the Programa de Controle de Emissões Veiculares (Proconve), being an example on a national scale.

The Institute for Energy and Environment (IEMA) survey confirmed the advances. In January 2021, 17% of the buses running in the state capital were diesel models manufactured before 2012 (which follow the P5 phase), with less effective pollutant control systems. The percentage of vehicles with this profile fell to 12% in August 2021.

There are also "cooperative" instruments widely used by cities in the transition phase. These instruments encompass a series of collaborative measures between civil society and municipal leaders whose efficiency depends on how they combine with the public policy of electromobility and the degree of cooperation between the stakeholders. The main function of these instruments is to provide knowledge to persuade stakeholders and engage in electromobility.

Figure 31 – Downtown Rio de Janeiro is a potential region to become a "low emission district" and receive electric bus lines

Credit: Pedro Bastos, ITDP Brasil (2021).

The C40 Green and Healthy Streets Declaration is a term of commitment that brings together more than 100 signatory cities willing to purchase zero-emission buses only from 2025 and ensure that at least one district of the city is a low-carbon district by 2030. This instrument seeks to engage municipal leaders to create an agenda of effective short, medium, and long-term actions. No control measures or sanctions are applied to signatory cities, but guidelines for the planning and implementing electric fleets, as well as criteria for transforming cities into greener, healthier, and more prosperous places. The City for The Climate of Rio de Janeiro Program was born from the support of the state capital to the commitment.

Rio de Janeiro was the 28th city in Brazil to join the Declaration of Green and Healthy Streets in 2019. Rio's participation led to the creation of the City for Climate Program (Rio Decree No. 46,079/2019), whose objective is to propose, plan and integrate the implementation of actions and projects aimed at reducing carbon indices, monitoring gas emissions, and reducing the impacts of climate change on the municipal perimeter. As a product, the Sustainable Development and Climate Action Plan (PDS) materializes a vision of the city collectively built for the next 30 years, predicting the decarbonization of transport as a goal and the Center of Rio as a "neutral neighborhood."

Aspiration: the city stimulates low-carbon urban development, promoting the use of clean technologies and energy efficiency and boosting the green economy.

Goals:

- MCR3.1: "Achieve in 2030 the reduction of 20% of GHG emissions of the municipality in relation to the emissions of the base year 2017, not contemplating the emissions of the steel industry, and in 2050 the neutralization of emissions, through the implementation of mitigation and compensation strategies";

- **MCR3.3: "Replace 20% of the Public Passenger Transport Service fleet by Buses with non-emitter vehicles, with impacts on reducing air pollution and urban noise";**

- MCR3.5: "Ensure that at least one area of the city has zero carbon emissions."

Another instrument with a similar function is the 2030 Agenda of the United Nations (UN), which also offers horizons of action to municipalities. For example, the decarbonization of urban mobility and the fight against climate change is part of all 17 Sustainable Development Goals (SDGs) across the board, especially the following: SDGs 5 (Gender Equality), SDGs 7 (Clean and Affordable Energy), SDGs 11 (Sustainable Cities and Communities) and SDGs 13 (Action Against Global Climate Change).

Race To Zero is an UN-backed global campaign that brings together city leaders and non-state stakeholders (businesses and investors) to support the healthy and resilient recovery of cities. The municipalities that sign the campaign sign a commitment term called Race to Resilience, and, in return, receive knowledge support, are involved in an international network of cities with electric buses, can negotiate more easily with investors, and enjoy assistance in the development of the program of electrification and supervision of planned deliveries. In this sense, the Race To Zero campaign acts as a facilitating tool for cities to acquire resources and feel encouraged to change. For example, in Brazil, the city of Salvador has received support from the campaign to plan and execute its electromobility program, which, in 2021, was still in the testing phase.

Given the scarcity or lack of regulatory instruments, cities should ensure that contracts encourage the use of electric vehicles, understanding the potential and benefits they offer cities. The incentives need to be incorporated into the tender notices or the revision of contracts and can be fundamental for the transition to clean fleets in Brazil. Generally, contracts should ensure competitiveness, provide for the reduction or elimination of the emission of polluting gases, and the obligation to incorporate new technologies with sustainability certification and clauses that improve the quality of service.

Table 14 presents good practices of Brazilian cities identified in contracts in force in 13 Brazilian capitals by 2021. These best practices are recommended to cities reviewing public transport service concession agreements in the territories they are responsible for.

Table 14 – Good incentive practices in Brazilian contracts for the concession of public transport services by bus

Environmental	• Goiânia has established an Environmental Responsibility Program to monitor the goal of reducing 20% of greenhouse gases emitted within five years. • São Paulo defined a Steering Committee for the Fleet Replacement Monitoring Program for Cleaner Alternatives, demanded an annual emission report, and has set targets for reducing local and global pollutants within 20 years.
Financial	• São Paulo established fines and included remuneration criteria related to environmental goals. • Fortaleza has set fines if the provision of the service does not present technological innovations that add quality to the system. • Belém, Curitiba, Porto Alegre, and Recife introduced criteria in the remuneration formula related to improving the quality of service to the user.
Technical-operational	• Goiânia and São Paulo decided that fleet renewal should be done regularly and aim to reduce environmental impacts. • Brasília, Porto Alegre, Salvador, and São Paulo mentioned the change to electric buses as a parameter for renovation. • Recife mentioned that the renewal priority should be for older vehicles and that new vehicles must have a green seal. • Brasília and Goiânia highlighted the importance of covered and airy places for the supply of vehicles. • São Paulo has created a specific training program for technologies or actions that lead to the reduction of pollutant emissions.

Source: Own elaboration, from ITDP Brasil (2020a) [84].

5.2 GOVERNANCE MECHANISMS

Governance for implementing electric buses guides cities on how to delegate and assign responsibilities among the parties involved in the business model. In addition, it helps define the decision-making processes and determine how capital investments should be. To this end, cities must ensure that they have qualified human capital, i.e., stakeholders with the expertise, knowledge, and skills necessary to conduct the activities they are responsible for.

These components and the cooperation between the government and stakeholders allow cities to effectively manage the electric fleet operation. Furthermore, cities get inputs from mapping all the skills, knowledge, and skills required for executing the program steps to define the most appropriate mechanisms to foster and finance the electromobility program.

The main discussion point about governance is intrinsically related to financing issues. The most common approach for capital investments is the combination of financing mechanisms, such as concessions, subsidies, debt-borne loans, and rental contracts. Table 15 compares common financing schemes for electric buses, highlighting advantages and considerations that cities can consider during the implementation of project governance.

Table 15 – Comparison of common financing mechanisms for battery electric buses

Options	Advantages	Considerations
Costing with existing resources or subsidies	+ Common and simple model. + Resources do not need to be refunded. + Acts as a catalyst for transition.	- High initial burden. - It requires a large volume of resources or subsidies and is not possible everywhere. - It does not necessarily lead to a large-scale fleet transition.

Options	Advantages	Considerations
Debt financing, including concessional loans and green bonds	+ Distributes costs over time, allowing lower initial burden. + Concessional loans can offer flexible loans and much lower interest rates, making them more affordable.	- It may not offer enough financial support. - May require additional co-ordination between various stakeholders (if it involves loans from national and international development banks).
Leasing of components (batteries)	+ By transforming some capital costs into operating expenses, it balances initial and ongoing expenses. + Sometimes, it can be combined with better maintenance or replace-ment of components by manufacturers. + Allows the transition of the fleet on a large scale.	- Involves more stakeholders and divided responsibilities. - Attractiveness of the enter-prise and appetite of the market.
Operational leasing	+ Distributes the financing, allowing less concentration of the total burden in one of the parties. + Allows the transition of the fleet on a large scale.	- Involves more stakeholders and divided responsibilities. - Attractiveness of the enter-prise and appetite of the market. - It may increase in the long run as more parties get involved.
Financial leasing	+ Distributes the financing, allowing less concentration of the total burden in one of the parties. + It can be a much more robust option financially. + Allows the transition of the fleet on a large scale.	- Involves more stakeholders and divided responsibilities. - Attractiveness of the enter-prise and appetite of the market. - It may increase in the long run as more parties get involved.

Source: Own elaboration.

Due to the higher upfront costs of electric buses, some form of concession or budget financing is required until costs reach parity. The following items briefly deepen the analysis of each funding scheme listed in the previous table to guide cities on which mechanism to adopt.

Costing with existing resources or subsidies In this mechanism, the operator assumes capital costs through direct budget support or subsidies. Direct purchases with public budget resources are common in Europe and the United States, where state entities manage public transport. However, in regions with limited resources, as may be the case in Brazilian cities, this option generally becomes unfeasible. In addition, when operations are outsourced, some form of granting resources or support can also help reduce the need for funding, as governments often help the private sector mitigate the risks of adopting new technologies or innovations.

In the case of direct contribution and combined costing with other financing mechanisms, it is common to use subsidies or similar financial opportunities to acquire electric buses. Direct purchase with subsidies is essential (although declining) in China, where government subsidies since 2009 have allowed for exponential growth in electric bus markets and new technologies.

Debt financing, including through concessional loans and green bonds In this mechanism, the public transport agency or operator uses flexible loans for capital costs, refunding the creditor(s) for a certain period. Such creditors may be national and international development banks or environmental funds, such as the Green Climate Fund or the Global Environmental Facility, whose motivation is to promote urban development and meet climate change goals.

Concessional loans to operators offer flexible lending conditions -- such as low-interest rates or longer repayment schedules -- that represent a more financially durable alternative to the final purchase.

This mechanism was used in Curitiba (the operator bought Volvo hybrid electric buses with a flexible loan from BNDES, the National Bank for Economic and Social Development of Brazil) and Bogotá (similarly, operators received financial support from Colombian bank Bancoldex, which received support from the Inter-American Development Bank, BNDES and the Swedish Export Credit Agency). One part of the loans is destined for capital financing, and the other is for debt financing. The amount of capital financing determines how much debt financing service fees need to be covered by operating expenses.

This mechanism is increasingly being used as more and more development banks work with such loans, and capital costs decrease as battery prices and charging infrastructure drop. For example, Tamil Nadu, a state in southern India, is acquiring electric buses through a loan from KfW (German Development Bank), with most being deployed in the capital, Chennai. Like concessional loans and subsidy mechanisms, green bonds are used to reduce initial financial constraints. This mechanism uses green bonds where 95% of bond yields contribute to environmentally beneficial projects — in this case, the electrification of public transport. This innovative financing mechanism has already been used in Tianjin, China, and is increasingly common in Sweden.

Leasing of components (batteries). In this model, the operator or local government rents the bus and/or battery from the manufacturer or supplier (often with the support of a third-party investor, such as a development bank or a niche financing company) to reduce the initial financial risk of a lease of its own. The arrangement is called battery leasing. By separating the purchase of some components (such as infrastructure) and the rental of other components (such as buses and/or batteries), the initial cost is comparable to that of diesel and CNG buses. This benefits manufacturers by expanding the market of transport operators interested and able to fund electrification in this way. It also benefits operators by making electric buses a viable financial option both at the beginning and during the life of vehicles.

Third-party investors, such as development banks, are motivated to support electrification projects to achieve environmental and social objectives. In addition, the leasing contract is not always the only financial mechanism —it can be adopted in parallel with subsidies or loans to reduce upfront costs further. For example, this arrangement was used in Bogotá, Colombia, with Volvo, in conjunction with a loan to operators for the acquisition of hybrid electric buses, as well as in Park City, Utah, USA, with the company Proterra.

Similarly, in São Paulo, battery leasing was used to purchase 15 battery electric buses in 2018. For the pilot project, BYD helped finance the vehicles (with 20% entry and the rest in 60 months with market rates). The city signed a battery rental contract (R$ 9,500.00/month, equivalent to about US$ 1,700/month) to be paid in 15 years. In this way, funding programs can help reduce barriers to fleet financing and the initial pilot project.

In addition to the benefit of reducing upfront costs, in the case of batteries, leasing agreements can offer battery life guarantees, battery performance guarantees, and/or replacement with new batteries in the middle of life. The latter option is particularly beneficial as operators can obtain a battery with more advanced technology at no exorbitant cost. Unfortunately, there is relatively limited information on good battery leasing practices in Bogotá and other cities, but growing interest in this model should result in good practices in the coming years.

Operational leasing. In this model, a third party acquires the agreed assets (e.g., buses) and leases such assets and/or infrastructure for operations. A public service ownership agreement can be an operating lease (or leasing). Cities such as Santiago, Chile, and Portland, Oregon, USA, used this model with utilities that acted as asset or infrastructure owners. For example, in Santiago, two separate concessionaires own the buses and rent them to transport operators.

Different variations of this model are increasingly popular. By separating upfront costs between the various stakeholders, the model can alleviate the high-cost capital challenges for the operator and provide different benefits to stakeholders. For example, for the manufacturer, this increases sales; accelerates electrification without generating huge financial responsibilities; for the owner of the buses/batteries (such as a utility company), it generates additional revenue and creates a stronger balance sheet; and for the capital provider, it expands its autonomy in the electric bus market while ensuring a stable return from the lessor.

Financial leasing. There are several types of financial leasing contracts, such as direct leasing, after-sales lease, and trust lease. The model is similar to a loan and often involves multiple stakeholders. However, it is different from leasing components (buses/batteries) and operational leasing by including another interested party with capital for the rental resource. Often, the financial leasing company buys the buses with or without batteries and rents the fleet to the bus operator, who pays the rent for a certain period.

The contract must stipulate that buses should be rented with the battery for a certain period (e.g., 15 years); and that the lessor must provide a battery change after a certain period (seven or eight years) or when the batteries exceed a certain percentage of their initial capacity. The bus operator pays the initial cost and interest on the buses, and the financial leasing company has guaranteed revenue over time.

The most notable example of a financial leasing agreement is Shenzhen, China, where the municipal government, bus company, operator, financial leasing company, and electric bus production companies signed a contract to purchase and sell electric buses. In this case, the financial leasing company acquired only the buses (not the batteries) and rented the fleet to the service operator, who began to pay rent for a specified period (in this case, eight years).

BYD sold the batteries to the China Putian Information & Industry Group, which received payment for the services of the Shenzhen bus company. In this scenario, the bus operator is guaranteed a slow and longitudinal financial obligation, paying both the initial amount and interest on the buses, and the financial leasing company has guaranteed income over time. Variations of the mechanism were also used in New York, USA, and Warsaw, Poland.

5.3 GUIDELINES FOR EFFECTIVE OPERATIONALIZATION

Transitioning to a large-scale electric fleet depends on actions that allow and facilitate day-to-day operation. Collecting data to make the system's operation more predictive, avoiding failures, claims, and other irregularities impairing the effective service provision.

The main orientation that cities should consider is the need to monitor the operation. This applies not only to the pilot phase but also to when vehicles are permanently circulating. The permanent operation does not exempt the service from failures and irregularities that require reviewing fleet planning, route planning, and vehicle technical specifications. The more evidence is collected, the lower the long-term risks of a problematic and inefficient transition.

Monitoring is essential to understand how buses behave in the face of the local scenario and the elevation, topographic variation, and road priority conditions. As the fleet expands, it becomes easier to operate in areas that were not served until then. If reliable and accurate, the data collected during monitoring can dispense with the execution of pilot projects in future areas served.

Another primary orientation is to ensure the **preservation of battery life**. Some routes can be more or less challenging for autonomy (~250 km), depending on the distance from garages and the location of charging infrastructures. This involves thorough planning between route optimization and vehicle loading to avoid service interruptions.

This concern also applies to access to the electricity itself. Increased fleets can directly interfere with distribution network load variations, especially during peak times and/or warmer months, when electricity consumption also affects the regular operation of the network as a whole. **Ideally, cities should previously review the possibility of marketing electricity through a free market to ensure that the fleet is adequately supplied.** Another practical guideline is to ensure that the charging infrastructures purchased or rented are compatible with the city's electrical system.

In addition, as discussed in item 1.4, one of the barriers faced is the standardization of infrastructure and other components. The scarcity of suppliers and manufacturers favors the learning of drivers and technicians in operation and maintenance. Consequently, it influences how they relate and manipulate equipment, as cities tend to purchase or rent equipment from the same manufacturer or supplier. On the other hand, the trend is for the sector to grow and for the bargaining power of cities and stakeholders to increase for acquiring and leasing these infrastructures. The expected result is for cities to save more in purchasing these assets, but they are forced to deal with the burden of maintaining infrastructure regarding different specifications.

To mitigate the standardization challenge, the Combined Charging System (CCS) was created based on universal standards for electric vehicles to ensure interoperability between vehicles and components from different manufacturers [85]. However, even with advances in standardization on the horizon, **cities are recommended to seek continuous training to deal with the new technologies that arise**. This reduces the dependence on certain manufacturers and suppliers while investing in continuous training and personnel training can help them operate equipment of different sizes and specificities.

For drivers, it is essential to highlight the training oriented to the greater energy use of batteries. Although electric motors are more efficient than combustion engines, inadequate acceleration may require battery overload, reducing battery life. In addition, with a smoother deceleration, the energy used in the regenerative braking process has greater potential to be reversed to charge the battery, extending its autonomy [86].

Figure 32 – Employing women to drive vehicles increases gender parity in the transport sector and ensures an operation with less likelihood of accidents and infractions

Credit: Emol (2016).

Cities should incorporate progressive gender parity targets in the composition of the workforce responsible for operating electric buses, especially in the role of drivers. In 2021, the passenger transport sector had about 2.2 million workers, with only 17% women. In addition to being a key strategy to reverse a predominantly male situation, female drivers are proportionally responsible for fewer traffic offenses, deaths, and traffic accidents [87].

In Guadalajara, Mexico, more than half of the people who drive electric buses are women [88]. In Chile, Transantiago's bid innovated by awarding the best driver among the concessionaires [89]. The award consists of a financial incentive and lectures in schools and universities to demonstrate the importance of greater inclusion of women in the transport sector. This is a measure that cities can (and should) consider for an emerging niche, such as electric buses, ensuring diversity, equity, and inclusion.

Cities must also **ensure that the inclusion of electric buses is accompanied by effective measures to avoid congestion**. To a large extent, zero-emission vehicles solve problems related to air quality. On the other hand, they are vehicles that congest streets and avenues, like diesel buses. **The Avoid-Change-Improve approach should guide planning in the effective transition to electric fleets.** It is not enough to incorporate zero-emission vehicles into the public transport system; it is necessary to adapt the road system, prioritizing pedestrians, cyclists, and electric buses. This makes the system more inclusive and efficient. In addition, it is worth mentioning a technical justification: when electric buses spend less time in traffic jams with the engine running, the battery life is better used. As a result, buses can make more trips and transport more people, contributing to better use of invested resources and less environmental impact.

Finally, one last orientation is to **ensure the population's involvement, especially in planning routes**. Quality public transport needs to focus on user satisfaction. This factor is crucial to retain and attract people, especially those who are users of other modes of transport that need to be discouraged, such as cars. Although electric fleets require an optimized route to meet their operational needs, cities must reconcile users' technical demands and demands. Many routes defined behind closed doors by decision-makers do not satisfactorily meet the population's day-to-day life. Interestingly, cities regularly conduct opinion polls to identify users' profiles of the lines and, in this way, adopt adjustments and improvements that favor the transport experience.

6.

MONITORING AND EVALUATION

This chapter lists the main instruments for monitoring the efficiency of electric buses that have already been used in several regions of Brazil and some countries in Latin America and the United States. Then, the main procedures for planning and structuring projects, mobilization of financing, monitoring, and evaluation are addressed. Finally, recommendations adapted to the Brazilian reality are presented, articulating them to the results and analyses presented in the previous items.

6.1 EVALUATION TOOLS

The acquisition of electric buses and batteries should be based on the successes and opportunities for advancement identified in the testing phases and from experiences shared by other cities because, as it is a new technology, there is still little public data on its operation in different routes and contexts.

The main evaluation tool for electric buses is pilot projects. They offer cities an estimate of how electric buses behave in local contexts and whether they can meet the needs and expectations of that city or metropolitan area, considering their transport challenges.

In this sense, the data collected during a pilot project are critical and determine whether the observed performance aligns with that expected of the buses. Therefore, cities should plan their pilot projects so that, after data collection, they can review planning, business models, and operation based on the evidence produced. Data should also be collected to evaluate the technology of the existing fleet, comparing conventional and electric buses.

The results of these pilot projects allow cities to make the necessary adjustments to the contracts for acquiring, operating and maintaining buses to be concluded with the companies. The goal is to ensure that any system changes are guaranteed. During the pilot project, the perception of drivers and passengers concerning the performance of the buses should be investigated. Some indicators are:

Table 16 – indicators of evaluation of electric buses pilot projects

General data	• Vehicle characteristics (e.g., model, weight, dimensions, battery capacity, etc.). • Weather conditions of the city or test site. • Qualitative perception of the satisfaction of users and drivers. - Internal lighting. - Cleaning. - Ventilation and temperature. - Visibility through the window. - Availability of places to travel. - Capacity/quantity of passengers. - Comfort of the seats. - Internal noise level. - Internal vibration level. - Conservation status. - Places of pick up and drop off. - Drivers' work (for users). - General satisfaction with the experience.
Cost data	Capital costs • Vehicle. • Charging infrastructures. Operating costs • Electricity rate. • Bus maintenance. • Infrastructure maintenance.
Operational data	• Topographic conditions. • Extension traveled with road priority in the planned route. • Number of pick up and drop off points. • Daily mileage traveled per vehicle. • Average daily route. • Average speed per trip. • Vehicle availability. • Energy consumption per trip. • Passengers transported per trip. • Passenger rate per km.
Charging data	• State of charge per vehicle (SoC). • Average charging time spent per vehicle. • Energy costs.

Maintenance data	• Reason and duration of maintenance stops • Average mileage between failures • Failure rate per month • Qualitative perception of the challenges of maintenance and satisfaction of the professionals responsible for this function
Data on environmental benefits	• Energy saving • Avoided greenhouse gas emissions • Avoided emission of local pollutants

Source: Own elaboration based on the activities carried out within the framework of the Tumi E-bus Mission and ITDP (2021).

In addition to pilot projects that each city can prepare in its own way, there are free tools that support simulation, evaluation, and monitoring of scenarios. System operators should monitor operational data for different routes when planning new or adjusted routes. For example, in U.S. cities, pilot projects in King County, Washington state, and Albuquerque, New Mexico, faced challenges with battery depletion due to weather and topography (very cold and mountainous in the first case and very hot in the second). Observing this data in the early (or even mature) phases of electric bus fleets can help model efforts and other forms of analysis that can adjust operator behavior, route requirements, and system planning. Annex 1 lists the main strategies and evaluation and monitoring tools available.

6.2 LESSONS LEARNED

Incorporating new technology, such as electric buses, depends on several factors, from normative and regulatory instruments and arrangements to the availability of financial resources. When the transition is planned to occur at scale, understanding and considering local opportunities and conditions helps the process move faster. In addition, understanding the internal and external driving forces that affect the supply and demand of electric buses and their components also influence decision-making.

Regardless of the tools adopted and/or the transition stage, it is important to emphasize that the cities that adhered to electromobility are still learning to deal with the challenges of operating a technology that, until recently, was unusual in public transport systems.

Given this learning process, general lessons are shared on a national and international scale that have already become recommendations for cities in implementing electric fleets. The following lessons are cross-cutting and summarize some of the topics presented throughout this technical guide.

6.2.1 Pilot projects

The cities that conducted pilot projects could identify their technical staff's training level and the main bottlenecks to operating electrical fleets properly in practice. With this data in hand, planning the effective implementation of an electric bus system has become less challenging. In addition to optimizing resources, pilot designs allow experiencing battery life and vehicle resistance when traveling in realistic local conditions. In addition, they are a stage of great value for cities to assess the quality of production of different manufacturers and, thus, identify the most appropriate technical specifications for their local urban conditions. Pilot projects should be systematically monitored by scripted indicators and metrics (as recommended at the beginning of this chapter).

6.2.2 Business models

Risk sharing helps overcome the high upfront costs of acquiring electric buses, ensuring that vehicles remain accessible to all parties involved —especially users. In addition, the model of separation of asset provision contracts (vehicles, charging infrastructures, land, among others) and operation facilitates the participation of new stakeholders with the greater financial capacity to "head" the project through more robust financing and credit programs to enable electrification at scale.

Cities should also remember that each investment component should remunerate those who finance and acquire the fleet and infrastructure separately. This helps reduce the risk of the operator not recovering the investment made in the business and allows to use Capex savings to cover Opex expenses.

6.2.3 Deadlines and schedules

Cities can set clear expectations with all stakeholders and draw realistic timelines. The diagnostic stage ("Is the city able to receive electric buses?") collaborates both to define the best business model and to identify possible limitations and funding opportunities early in the project (such as planning capacity and political support).

Cities that have already adhered to electromobility have learned that conservative timelines for each stage of the planning process are critical not to frustrate expectations and thus allow for a gradual but effective transition. This can help prevent financial or human resources from being misused.

The duration of contracts must be defined to enable the continuous quality of the service, maintain the predictability of investments and ensure the competitiveness of the bidding process. In addition, the duration of the contract influences greater or lesser flexibility to enable changes in the bus transport sector in response to new environmental and technological requirements or structural changes in urban mobility standards. Moreover, it affects the willingness of operators to invest more or less in the service.

In this sense, the time of provision or possession of conventional and electric vehicles must be different in contractual terms. The contract duration should be up to 15 years for electric buses and up to ten years for other vehicular technologies. In the latter case, stipulating operating times of less than ten years facilitates the guarantee of incorporation of technological updates and greater competitiveness.

Although they offer greater security to operators, long terms can also stimulate market dominance by a few companies, to the detriment of improvements for users. Shorter contracts promote greater competition in the sector. Besides, they need adequate investment costs and may demand more government management actions. Therefore, the definition of the contract duration requires a balance between the specific constraints of each city.

6.2.4 Varied portfolio of revenues

In most concession contracts in Brazilian cities, remuneration is a priority of the tariff nature. This means that the more the city attracts passengers, the more resources are available to offer quality service and ensure their compensation. However, it is of utmost importance that there are other collection sources. Demand fluctuations or health crises threaten remuneration through tariffs.

As chapters 2 and 3 show, additional sources may be government subsidies, commercial and/or advertising exploitation at bus stops, stations, and terminals, taxation incentives, urban planning instruments to capture real estate valuations, or GdM measures, such as congestion pricing. The possibilities are many and with varying degrees of implementation difficulty. Nevertheless, the cities have learned that, with creativity and political will, it is possible to change the public transport system and several other aspects of urban life, thus promoting integrated and equitable urban planning.

6.2.5 Incentive policies

Cities can accelerate this process with articulated incentive policies and strategies —such as Chile and Mexico. Additionally, the policy should be aligned with environmental and sanitary agendas and consider intersectionalities of gender, race, and income.

As we have seen, the business model must be able to enable technology in the long run, even at a higher initial cost. For this to occur, engaging and aligning several stakeholders (governments, operators, investors, manufacturers, and technology suppliers) is necessary for a beneficial change with manageable risks for all.

Improving competition in the market and concession processes can promote the deployment of clean buses. Cities such as Santiago (Chile) and Shenzhen (China) have, for example, encouraged the participation of third parties, such as car and energy rental companies, to share financial burdens and risks and expand possibilities.

Revenue sources also involve other stakeholders. For example, toll collection of private vehicles and other GdM measures can be used to finance the system. However, an external entity should administer these resources to the supply concessionaires or the undertakings responsible for the fleet operation.

Ensuring competitiveness and competition in contracts through the absence of garage ownership requirements by competing companies also allows the entry and participation of other parties in the process, enabling the involvement of stakeholders and manufacturers capable of heating the market of electric vehicles and their components in the country.

6.2.6 They retain users and resignify the image of public transport

Public transport by bus is historically stigmatized by many cultural factors that challenge cities engaged in boosting electric fleets and make it difficult to attract new users to ensure the system's financial balance. In this sense, one of the main lessons learned by cities that, to a greater or lesser extent, faced financial and social challenges in public transport (and which have been managing to conduct modal migration for buses) are the factors "**quality**" and "**innovation**."

The "**quality**" of service (as a synonym for comfort, reliability, and coverage) is essential to attract the target audience's attention, a target likely to opt for individual transport over the bus. In addition, if buses run on segregated roads, the likelihood of reducing travel time gives public transport even more advantages.

"**Innovation**" has also undoubtedly proven electric buses' competitive advantage. Users and non-users are curious to know the new technology and try it. If cities can implement communication plans that inform the population efficiently on electric buses' advantages (in addition to their greater comfort and quality, that is, disseminating their real health and environmental benefits), the engagement of the population may be potentially greater, opening opportunities to resignify the image of public transport.

6.2.7 Regular capacitation

Technical training programs should be regular and mandatory activities in the stipulated business models. They should engage managers and operators to ensure efficiency in the use, monitoring, and supervision of the system.

Electric buses and their components have specific operating and maintenance characteristics per supplier. In addition, weather and topographic conditions and how vehicles are driven (depending on average speed) dramatically influence battery performance.

Training should always consider incorporating knowledge of new technologies to improve service and energy efficiency. Capacitation and training should also specify the interaction between staff, operators, and partners and the management of new equipment and specific technologies [90].

For drivers, for example, it is necessary to consider the maximum distance on their routes from the battery level, considering the time of return to the charging infrastructure. They also need to be instructed on how to extend battery life by driving the vehicle in the best possible way. Regenerative braking, one of the performance attributes of electric vehicles, can increase battery capacity and battery life by up to 20%. However, it is necessary to know how to operate it properly. Therefore, training has proven to be a key element in preserving the longevity of these assets.

6.2.8 Flexibility to implement electric buses

Brazilian medium-sized cities have shown more success and ease in implementing electric buses than large centers. While electric buses are essential to mitigate accessibility problems and climate change in large urban centers, where these challenges are greatest, the complexity of planning and scalability are factors that do not affect medium-sized cities in the same way. The high cost of acquiring electric buses ends up being offset by the need not to operate a large-scale fleet. In ideal cases, this allows municipalities to make more agile decision-making, opening opportunities for the electric bus revolution to gain momentum from places where technological innovations generally tend to be incorporated later into capitals or large cities.

7.

FINAL CONSIDERATIONS

Cities must adhere to electromobility, which should occur from public transport by bus. The scale adoption of clean technology with proven potential to become financially sustainable in the medium and long term is more than necessary to reverse the current economic situation of the systems, which depend almost exclusively on the tariffs users pay and face challenges to adapt to fluctuations in demand.

In addition, the post-covid-19 gradual recovery scenario also needs to offer integrated solutions for improving air quality and preserving the population's health. Electromobility is the opportunity that municipal leaders have to offer a more sustainable, healthy, and inclusive urban development in the future, with effective and immediate impacts. Moreover, cities play a crucial role in intensifying a more effective transition of the Brazilian energy matrix.

Some barriers still discourage cities from joining the transition to electromobility in public transport (including technological market, financial and regulatory issues). This Technical Reference Manual aims to illuminate the pragmatic paths that cities must follow to make electromobility a financially and technically viable possibility, socially responsible, and environmentally appropriate.

The main strategies and tools used by pioneer cities (from Brazil and worldwide) that successfully adopted electric buses were presented throughout the chapters. Promoting fleet replacement is not yet a simple task. Different solutions must be considered and assessed for each city according to their geographical, institutional, financial, and cultural reality.

Lessons learned show that short-, medium and long-term actions involving all stakeholders are needed to achieve more ambitious fleet decarbonization goals. Integrated and coordinated measures need to be adopted at the three levels of government (federal, state, and municipal), and such measures need to be articulated with fomentation and funding agencies, operators, and other potential new market stakeholders.

Faced with these challenges, the revision of the regulation plays a decisive role, capable of influencing the transition to electric buses in Brazil. Therefore, a policy should be structured for the segment, defining specific rules that establish financial, regulatory, environmental, and operational incentives. Business models are the first step. They must be designed to ensure flexibility, stability, sustainability, and, especially, continuity of service.

The use of electric buses cannot be restricted to pilot projects. Instead, adopting these vehicles should evolve in scale, expanding coverage with a focus on the target audience and the most vulnerable territories. For this to be possible, the elaboration of scenarios with clear and realistic goals (but also bold) must be on the agenda.

Some policy instruments, such as the C40 Cities Declaration of Green and Healthy*Streets*, illustrate the goals assumed by cities in transition. The São Paulo Climate Law is also a great example of how cities can be inspired and engaged in eliminating local polluting gas levels within a 20-year horizon. These gases are the most harmful to human health, and adopting electric buses is the most promising and viable solution to mitigate them.

Finally, the exchange of experiences and collaboration between cities is recommended to be expanded and strengthened. Most committed municipalities are still learning how to make the best transition possible. The shared and transparent management of information, facilitated, in many cases, by civil society organizations, helps in a relevant and impactful way in the planning and effective implementation of the electromobility project of the city.

8.

APPENDIX

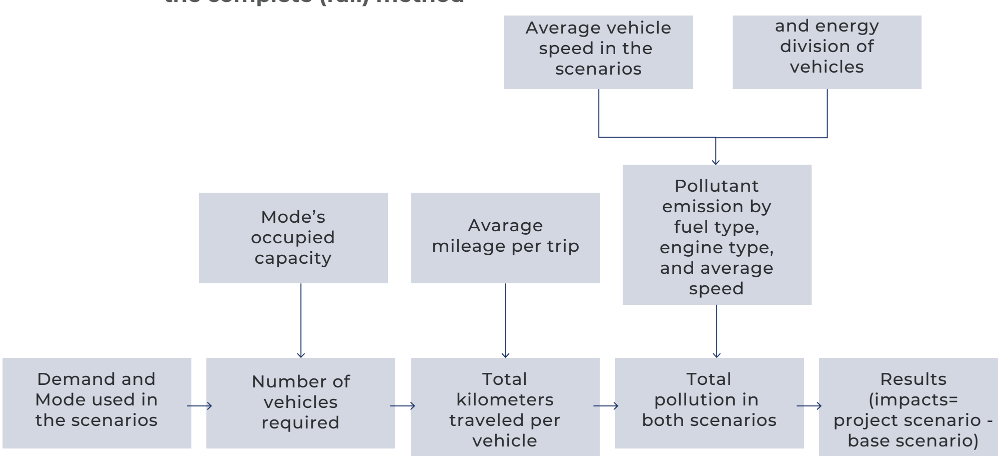
APPENDIX 1: EXAMPLES OF EVALUATION TOOLS

1. Transport Emissions Evaluation Models for Projects (TEEMP)

Developed by the Clean Air Initiative for Asian Cities and ITDP, it assesses the impact of new BRT corridors to be implemented or in operation in terms of greenhouse gas emissions and local pollutants, considering the different existing vehicle technologies and including electric buses in the fleet.

How does it work? The TEEMP model calculates the total emissions avoided by implementing a new BRT corridor. Thus, emissions from a base scenario without the project implementation are compared with those of the post-project scenario. The TEEMP model offers a simple alternative (shortcut method or shortcut) and a complete (full or full method, as shown in Figure 33).

Figure 33 – Flowchart of the steps for calculating emissions in the complete (full) method



Source: ITDP (2022) [91].

The direct impacts of TEEMP application on both alternatives result from the following factors:

- Modal transition resulting from project implementation;
- Reduction of mileage traveled by the reorganization of lines;
- Energy efficiency through optimized operation and the use of less polluting fuels (in terms of local pollutants);
- More efficient vehicles, in terms of grams of CO_2 per passenger per kilometer, given the renewed fleet or the increased capacity of the vehicle;
- Encouraging a more compact development from possible land use changes decreases dependence on private cars, induces modal transition, and decreases the distances traveled at each displacement. This is considered a secondary indirect impact because it depends on the existence of specific policies.

Guidelines: To be parameterized according to the local technological and energy reality of Brazil, it is recommended to complement the completion of the spreadsheet with the following:

- Updated data from the National Inventory of Atmospheric Emissions by Road Motor Vehicles of the Ministry of Environment;
- Data provided by the managing body or public transport operator in the locality studied;
- Data obtained through field research.

Particularities: Available only in English, last updated in 2015.

How to access? Excel file for download and fill in: https://www.itdp.org/2012/08/06/transport-emissions-evaluation-model-for-projects-teemp-brt/.

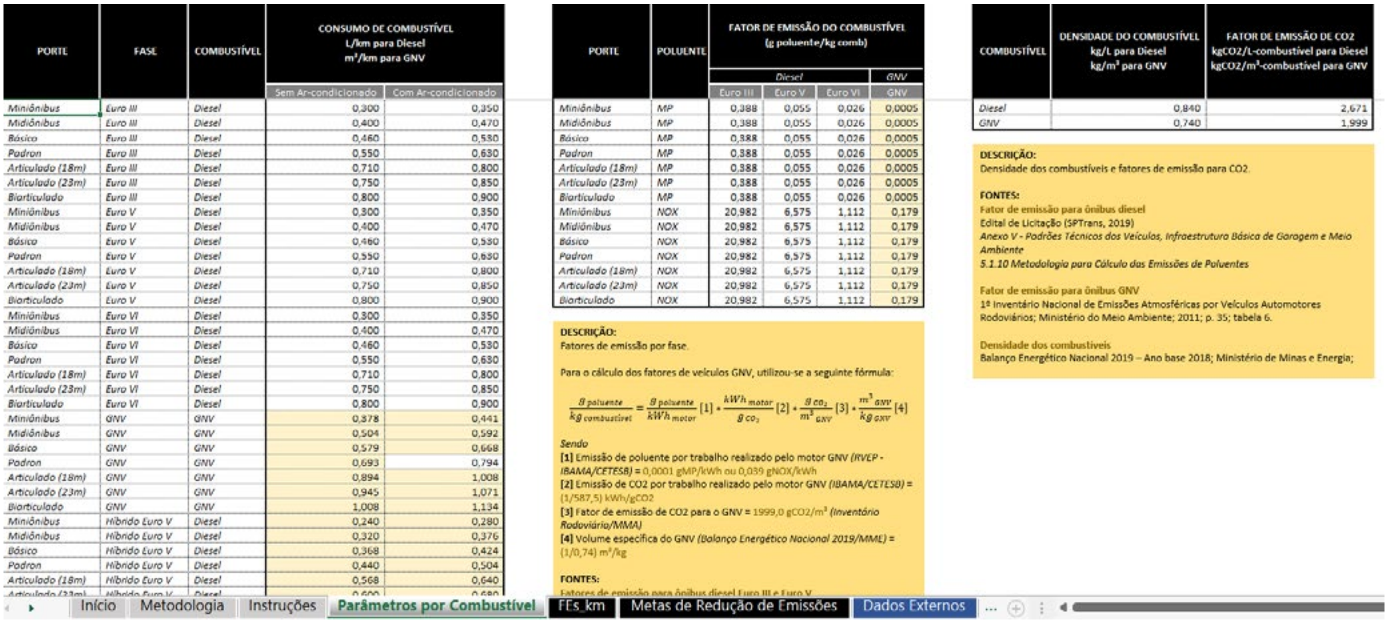
2. PlanFrota: tool for clean transport

Developed by IEMA with the support of the Instituto Clima e Sociedade (iCS) and SPtrans partnership, the tool allows the simulation of scenarios that illustrate emissions of carbon dioxide (CO_2), particulate matter (PM), and nitrogen oxides (NO_x) — local polluting gases that are harmful to health — in different technological configurations of bus fleets in a transport network.

How does it work? The user chooses the profile of the bus fleet to calculate emissions specifying technology, fuel, use of air conditioning, and size of each vehicle, considering the years 2019 to 2038. As each technology used in buses and each fuel emits different pollutants more or less intensely, the tool evaluates the impact of the use of each of them on the city's emissions.

Bus operators are using the tool to plan the renewal of the fleet of the city of São Paulo according to the gradual reduction targets provided for in the Climate Law (16.802/2018). In addition, PlanFrota can be used by civil society to monitor the adoption of clean buses and propose strategies and solutions that respond to this challenge.

Figure 34 – Tool interface



PORTE	FASE	COMBUSTÍVEL	CONSUMO DE COMBUSTÍVEL L/km para Diesel m³/km para GNV	
			Sem Ar-condicionado	Com Ar-condicionado
Miniônibus	Euro III	Diesel	0,300	0,350
Midiônibus	Euro III	Diesel	0,400	0,470
Básico	Euro III	Diesel	0,460	0,530
Padron	Euro III	Diesel	0,550	0,630
Articulado (18m)	Euro III	Diesel	0,710	0,800
Articulado (23m)	Euro III	Diesel	0,750	0,850
Biarticulado	Euro III	Diesel	0,800	0,900
Miniônibus	Euro V	Diesel	0,300	0,350
Midiônibus	Euro V	Diesel	0,400	0,470
Básico	Euro V	Diesel	0,460	0,530
Padron	Euro V	Diesel	0,550	0,630
Articulado (18m)	Euro V	Diesel	0,710	0,800
Articulado (23m)	Euro V	Diesel	0,750	0,850
Biarticulado	Euro V	Diesel	0,800	0,900
Miniônibus	Euro VI	Diesel	0,300	0,350
Midiônibus	Euro VI	Diesel	0,400	0,470
Básico	Euro VI	Diesel	0,460	0,530
Padron	Euro VI	Diesel	0,550	0,630
Articulado (18m)	Euro VI	Diesel	0,710	0,800
Articulado (23m)	Euro VI	Diesel	0,750	0,850
Biarticulado	Euro VI	Diesel	0,800	0,900
Miniônibus	GNV	GNV	0,378	0,441
Midiônibus	GNV	GNV	0,504	0,592
Básico	GNV	GNV	0,579	0,668
Padron	GNV	GNV	0,693	0,794
Articulado (18m)	GNV	GNV	0,894	1,008
Articulado (23m)	GNV	GNV	0,945	1,071
Biarticulado	GNV	GNV	1,008	1,134
Miniônibus	Híbrido Euro V	Diesel	0,240	0,280
Midiônibus	Híbrido Euro V	Diesel	0,320	0,376
Básico	Híbrido Euro V	Diesel	0,368	0,424
Padron	Híbrido Euro V	Diesel	0,440	0,504
Articulado (18m)	Híbrido Euro V	Diesel	0,568	0,640

PORTE	POLUENTE	FATOR DE EMISSÃO DO COMBUSTÍVEL (g poluente/kg comb)			
		Diesel			GNV
		Euro III	Euro V	Euro VI	GNV
Miniônibus	MP	0,388	0,055	0,026	0,0005
Midiônibus	MP	0,388	0,055	0,026	0,0005
Básico	MP	0,388	0,055	0,026	0,0005
Padron	MP	0,388	0,055	0,026	0,0005
Articulado (18m)	MP	0,388	0,055	0,026	0,0005
Articulado (23m)	MP	0,388	0,055	0,026	0,0005
Biarticulado	MP	0,388	0,055	0,026	0,0005
Miniônibus	NOX	20,982	6,575	1,112	0,179
Midiônibus	NOX	20,982	6,575	1,112	0,179
Básico	NOX	20,982	6,575	1,112	0,179
Padron	NOX	20,982	6,575	1,112	0,179
Articulado (18m)	NOX	20,982	6,575	1,112	0,179
Articulado (23m)	NOX	20,982	6,575	1,112	0,179
Biarticulado	NOX	20,982	6,575	1,112	0,179

DESCRIÇÃO:
Fatores de emissão por fase.

Para o cálculo dos fatores de veículos GNV, utilizou-se a seguinte fórmula:

$$\frac{g_{poluente}}{kg_{combustível}} = \frac{g_{poluente}}{kWh_{motor}}[1] \cdot \frac{kWh_{motor}}{g_{CO_2}}[2] \cdot \frac{g_{CO_2}}{m^3_{GNV}}[3] \cdot \frac{m^3_{GNV}}{kg_{GNV}}[4]$$

Sendo

[1] Emissão de poluente por trabalho realizado pelo motor GNV (IRVEP - IBAMA/CETESB) = 0,0001 gMP/kWh ou 0,039 gNOX/kWh

[2] Emissão de CO2 por trabalho realizado pelo motor GNV (IBAMA/CETESB) = (1/587,5) kWh/gCO2

[3] Fator de emissão de CO2 para o GNV = 1999,0 gCO2/m³ (Inventário Rodoviário/MMA)

[4] Volume específico do GNV (Balanço Energético Nacional 2019/MME) = (1/0,74) m³/kg

FONTES:

COMBUSTÍVEL	DENSIDADE DO COMBUSTÍVEL kg/L para Diesel kg/m³ para GNV	FATOR DE EMISSÃO DE CO2 kgCO2/L-combustível para Diesel kgCO2/m³-combustível para GNV
Diesel	0,840	2,671
GNV	0,740	1,999

DESCRIÇÃO:
Densidade dos combustíveis e fatores de emissão para CO2.

FONTES:
Fator de emissão para ônibus diesel
Edital de Licitação (SPTrans, 2019)
Anexo V - Padrões Técnicos dos Veículos, Infraestrutura Básica de Garagem e Meio Ambiente
5.1.10 Metodologia para Cálculo das Emissões de Poluentes

Fator de emissão para ônibus GNV
1º Inventário Nacional de Emissões Atmosféricas por Veículos Automotores Rodoviários; Ministério do Meio Ambiente; 2011; p. 35; tabela 6.

Densidade dos combustíveis
Balanço Energético Nacional 2019 – Ano base 2018; Ministério de Minas e Energia;

The figure shows a table of parameters per fuel with the following content: the size, phase, and fuel of the vehicle, their fuel consumption in L/Km for Diesel, and m²/ km for CNG, with and without air conditioning. It also shows the pollutant and the fuel emission factor for each vehicle size and the density of the fuels and CO2 emission factors.

Source: IEMA (2022) [92].

Particularities: The results are based on the emission factors of São Paulo and the consumption factors for diesel buses by the size of vehicles operated by SPTrans. Replication to other municipalities requires adaptations to parameterized data entry.

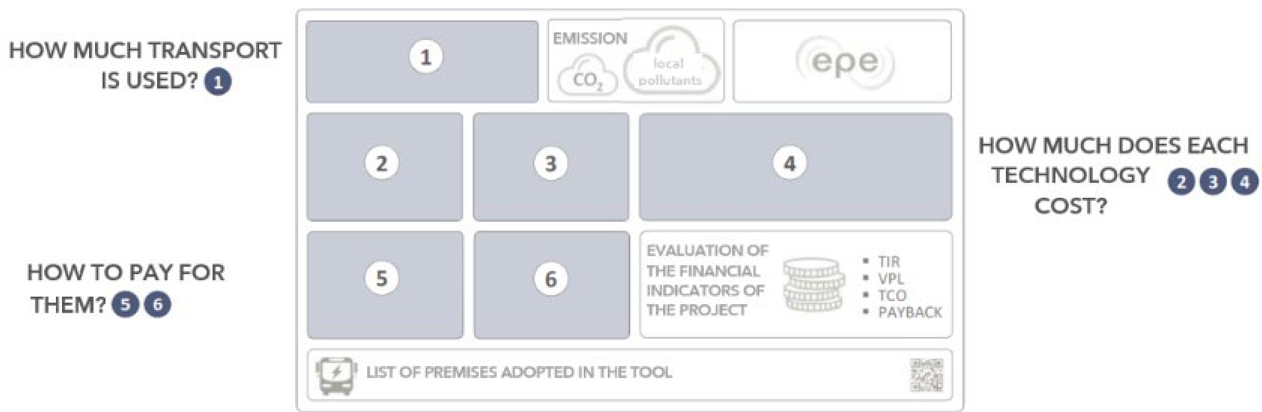
How to access? Excel file for download and fill in: http://energiaeambiente.org.br/wp-content/uploads/2020/02/20200602_planfrotanosite.xlsx.

3. Simulator for Feasibility Assessment of Electric Bus

Developed by the Energy Research Office (EPE), it allows making a technical and economic evaluation of electric buses. The main data generated by the simulator are the internal rate of return, the total cost of ownership (TCO), the net present value (NPV), and the return-on-investment time (payback).

How does it work? The tool requires the insertion of data on the average distance traveled and the days of bus operation per year; the number of electric buses that the city wishes to incorporate into the fleet; the price of diesel; the electricity distributor; the cost of purchasing a diesel bus; and the cost of equity (i.e., how much the city expects a return on its investments).

Figure 35 – Platform interface with thematic grouping of data entry by the user



Source: EPE (2022) [93].

Particularities: The list of premises adopted in the tool may present variables requiring completion attention. For example, the service life of buses is considered 5 years for diesel models and 10 years for electric (the present value of the technology in 2022 estimates useful life of 15 years). Another example is the price of a liter of diesel, whose reference by states dates from January 2019.

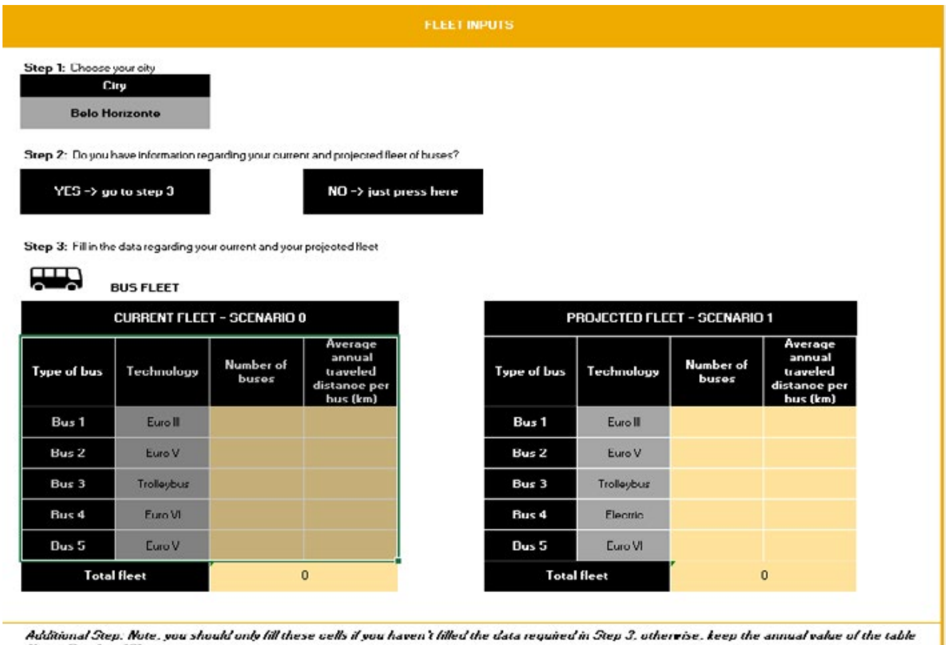
How to access? Excel file for download, or online fill in at: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/simulador-para-avaliacao-de-viabilidade-de-onibus-eletrico.

4. ImpactAr

Developed by WRI Brasil with the support of the Children's Investment Fund Foundation (CIFF), it evaluates health impacts according to air quality and calculates the monetary costs associated with changes in fleet emission levels. Supports decision-making for cities to measure changes in the number of hospitalizations and deaths and the financial and welfare costs linked to changes in urban air pollution levels.

How does it work? The tool is fed with information about current and projected fleets and provides annual variations in emissions and concentration levels of particulate matter (PM). With these data, it assesses the number of people and general epidemiological cases of cardiovascular and respiratory diseases (fatal and non-fatal) that can be at risk in a city and calculates its costs.

Figure 36 – Tool interface



Source: WRI (2022) [94].

Particularities: The tool is only available for São Paulo, Belo Horizonte, Rio de Janeiro, and Niterói but offers a replication manual for other municipalities. Updated in 2022.

How to access? Excel files and technical note in English for download and fill in: https://wribrasil.org.br/pt/publicacoes/impactar-ferramenta-valoracao-impactos-qualidade-do-ar-saude-onibus-eletricos.

5. Greenhouse Gases, Regulated Emissions, and Energy Use (Greet)

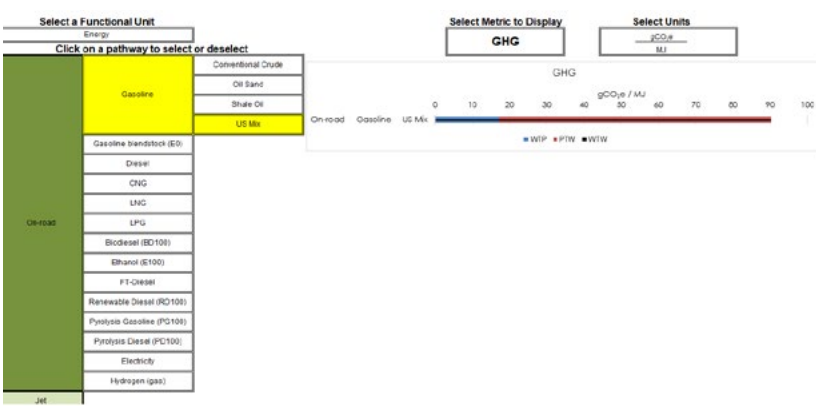
Developed by the Argonne National Laboratory of the University of Chicago in the United States, in partnership with the Scientific Office of the U.S. Department of Energy, the platform allows calculating the total energy consumption of an electric or hybrid vehicle according to the use of renewable or non-renewable sources of its engine. In addition, it can model a wide range of vehicles, including hybrid, battery-powered vehicles, and internal combustion.

How does it work? The platform consists of a set of calculators for different purposes. In the case of electric vehicles, two stand out:

- Greet WTW Calculator [well-to-wheel: describes energy use, greenhouse gas emissions, water consumption, and air pollutant emissions from different vehicle technologies using WtW analyses.

- Afleet Tool [Alternative Fuel Life-Cycle Environmental and Economic Transport Tool]: was developed to estimate oil use, greenhouse gas emissions, air pollutant emissions, and property costs of light and heavy vehicles.

Figure 37 – Tool interface



Source: GREET (2022) [95].

Particularities: Available in English. It can only be used on a Windows operating system with Microsoft .Net Framework 4.5 installed.

How to access? Software for download at https://greet.es-.anl.gov/.

6. E-Bus Radar

Developed by the Laboratory of Sustainable Mobility (LABMOB) of the Federal University of Rio de Janeiro (UFRJ), in partnership with the C40 network, ICCT, and IEMA and support from iCS, monitors and promotes data transparency on the expansion of electric buses in Latin American cities through a georeferenced panel.

Figure 38 – E-BUS RADAR platform interface

Source: E-BUS RADAR (2022).

How does it work? The tool monitors data on the vehicle technologies adopted, manufacturers, avoided emissions, and complementary quantitative analyses. Data presented on the Latin America, country, and city scales.

Particularities: Available in Portuguese, Spanish, and English. The data is updated every six months. In its latest update, it began to incorporate information about cities with bid fleets and/or are implementing them.

How to access? Online view at: http://ebusradar.org.

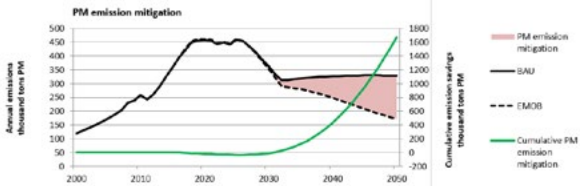
7. The eMob Calculator

Developed by UN Environment, it estimates the potential for saving energy and financial resources with the shift to electric mobility and calculating the reduction of greenhouse gas emissions and local air pollutants.

How does it work? The tool groups three calculators for the modes: motorcycles, light vehicles (including passenger cars and light commercial vehicles such as SUVs and delivery vans), and buses. The user must enter data such as projections of the gross domestic product (GDP) growth of the reference country, population growth, estimated vehicle sales, regional estimates on economic growth, fuel price, and carbon footprint of the electric matrix, among others. For large amounts of data, the tool recommends a consultation of the reference information base of the International Monetary Fund and the UN, for example.

Figure 39 – Calculator interface

DATA	Entity	Power-fuel	Unit	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
BAU			tons	119,3	128,7	138,8	149,8	161,6	174,4	188,1	202,9	230,4	238,5	259,2
EMOB			tons	119,3	128,7	138,8	149,8	161,6	174,4	188,1	202,9	230,4	238,5	259,2
PM emission mitigation			tons	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Cumulative PM emission mitigation			tons	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0



Saved NOx emissions		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
BAU	BAU	5964,6	6435,0	6942,4	7490,0	8080,7	8717,9	9405,5	10147,2	11519,4	11926,3	12958,1
EMOB	EMOB	5964,6	6435,0	6942,4	7490,0	8080,7	8717,9	9405,5	10147,2	11519,4	11926,3	12958,1
NOx emission mitigation	NOx emissi	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Cumulative NOx emission mitigation	Cumulative	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Source: UNEP (2022) [97].

Particularities: Available in English. By May 2022, the tool was being remodeled and not recommended for use and dissemination.

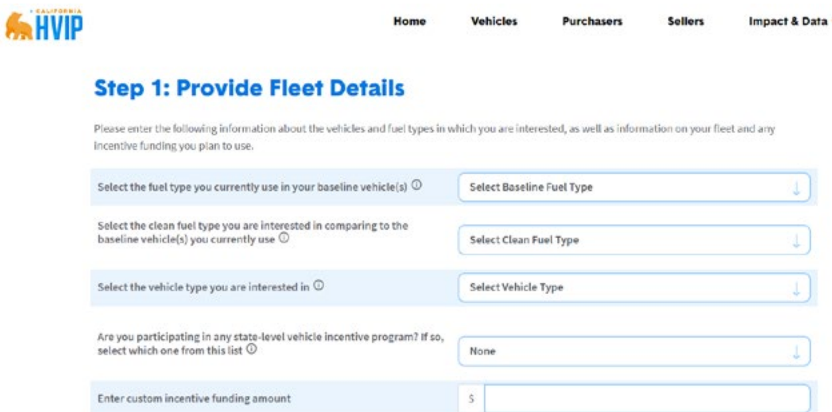
How to access? Excel files for download and fill in: https://www.unep.org/resources/toolkits-manuals-and-guides/emob-calculator.

8. Total Cost of Ownership Estimator

Developed by California's Hybrid and Zero-Emission Bus and Truck Voucher Incentive Project, the tool compares the estimated TCOs of zero- or nearly zero-emission buses and trucks with zero or near zero emissions and fossil fuel-powered vehicles such as gasoline, diesel, and vehicular natural gas.

How does it work? The tool requires the insertion of data on the vehicles to be compared, such as technical specifications, the purchase value of the vehicle and components, receipt of incentives or deductions, and taxes, among others.

Figure 40 – Tool interface



Source: HVIP (2022).

Particularities: Available in English. The data and results generated are limited to the United States.

How to access? Online filling in English.

9.

REFERENCES

[1] ICCT. **Benefícios de tecnologias de ônibus em termos de emissões de poluentes do ar e do clima em São Paulo**. Relatório Técnico. 2019. Available at: https://theicct.org/publications/beneficios-de-tecnologias-de-onibus-em-termos-de-emissoes-de-poluentes-do-ar-e-do-clima. Accessed in: June 2022.

[2] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Report. 2021. Available at: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Accessed in: June 2022.

[3] ICCT. **Benefícios de tecnologias de ônibus em termos de emissões de poluentes do ar e do clima em São Paulo**. Relatório Técnico. 2019. Available at: https://theicct.org/publications/beneficios-de-tecnologias-de-onibus-em-termos-de-emissoes-de-poluentes-do-ar-e-do-clima. Accessed in: June 2022.

ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Report. 2021. Available at: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Accessed in: June 2022.

[4] ICCT. **Benefícios de tecnologias de ônibus em termos de emissões de poluentes do ar e do clima em São Paulo**. Relatório Técnico. 2019. Disponível em: https://theicct.org/publications/beneficios-de-tecnologias-de-onibus-em-termos-de-emissoes-de-poluentes-do-ar-e-do-clima. Acesso em: junho de 2022.

ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID); MINISTÉRIO DO DESENVOLVIMENTO REGIONAL (MDR). **Guia de eletromobilidade.** Orientações para estruturação de projetos no transporte coletivo por ônibus. Brasília, 2022. ICCT. **Benefícios de tecnologias de ônibus em termos de emissões de poluentes do ar e do clima em São Paulo**. Relatório Técnico. 2019. Disponível em: https://theicct.org/publications/beneficios-de-tecnologias-de-onibus-em-termos-de-emissoes-de-poluentes-do-ar-e-do-clima. Acesso em: junho de 2022.

[5] E-BUS RADAR. **Plataforma de ônibus elétricos na América Latina**. Desenvolvido pelo LABMOB-UFRJ, em parceria com Zebra, C40, ICCT. 2021. Disponível em: ebusradar.org. Acesso em: junho de 2022.

[6] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[7] CARVALHO, C. H. R. Emissões relativas de poluentes do transporte motorizado de passageiros nos grandes centros urbanos brasileiros. **Texto para Discussão**, n.º 1606, Brasília, Instituto de Pesquisa Econômica Aplicada (Ipea). 2011. Disponível em: https://www.econstor.eu/bitstream/10419/91332/1/664398472.pdf. Acesso em: junho de 2022.

[8] CARVALHO, C. H. R. Emissões relativas de poluentes do transporte motorizado de passageiros nos grandes centros urbanos brasileiros. **Texto para Discussão**, n.º 1606, Brasília, Instituto de Pesquisa Econômica Aplicada (Ipea). 2011. Disponível em: https://www.econstor.eu/bitstream/10419/91332/1/664398472.pdf. Acesso em: junho de 2022.

[9] TAKANO, A. P. C. *et al*. Pleural anthracosis as an indicator of lifetime exposure to urban air pollution: An autopsy-based study in Sao Paulo. **Environmental Research**, 173, 23–32, 2019.

[10] ITDP Brasil. **Eficiência do uso do espaço em transporte segundo veículo**. Infográfico, 2015. Disponível em: https://itdpbrasil.org/programas/desestimulo-ao-automovel/. Acesso em: maio de 2022.

[11] WILT, J. **Do Androids Dream of Electric Cars**? Public Transit in the Age of Google, Uber, and Elon Musk. Toronto: Between the Lines, 2020.

[12] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[13] E-BUS RADAR. **Plataforma de ônibus elétricos na América Latina**. Desenvolvido pelo LABMOB-UFRJ, em parceria com Zebra, C40, ICCT. 2021. Disponível em: ebusradar.org. Acesso em: junho de 2022.

[14] BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID); MINISTÉRIO DO DESENVOLVIMENTO REGIONAL (MDR). **Guia de eletromobilidade.** Orientações para estruturação de projetos no transporte coletivo por ônibus. Brasília, 2022.

[15] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[16] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID); MINISTÉRIO DO DESENVOLVIMENTO REGIONAL (MDR). **Guia de eletromobilidade.** Orientações para estruturação de projetos no transporte coletivo por ônibus. Brasília, 2022.16 ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[17] BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID); MINISTÉRIO DO DESENVOLVIMENTO REGIONAL (MDR). **Guia de eletromobilidade.** Orientações para estruturação de projetos no transporte coletivo por ônibus. Brasília, 2022.

[18] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[19] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[20] NTU. **COVID-19 e o transporte público por ônibus:** impactos no setor e ações realizadas (16/03/20-15/04/20). Relatório. Disponível em: https://www.ntu.org.br/novo/upload/Publicacao/Pub637231535674949776.pdf. Acesso em: maio de 2022.

[21] NTU. **COVID-19 e o transporte público por ônibus:** impactos no setor e ações realizadas (16/03/20-15/04/20). Relatório. Disponível em: https://www.ntu.org.br/novo/upload/Publicacao/Pub637231535674949776.pdf. Acesso em: maio de 2022.

[22] IDB. Jobs in a net-zero emissions future in Latin America and the Caribbean. Relatório. 2020. Disponível em: https://publications.iadb.org/publications/english/document/Jobs-in-a-Net-Zero-Emissions-Future-in-Latin-America-and-the-Caribbean.pdf. Acesso em: junho de 2022.

[23] GRAMKOW, C.; MAGACHO, G. "O verde nas medidas para recuperação da economia nos EUA e reflexões para o Brasil". In: RONCAGLIA, A.; BARBOSA, N. (orgs). **Bidenomics nos trópicos**. Rio de Janeiro: FGV Editora, 2021. 286p. ePub.

[24] GOVERNO DO CHILE. **Plataforma de Electromovilidad**. Ministerio de Energía. 2021. Disponível em: https://energia.gob.cl/electromovilidad/transporte-de-pasajeros/buses-electricos-red. Acesso em: junho de 2022.

[25] JEREZ, P. O. O. **Evaluación Económica Y Social De La Incorporación De Buses Eléctricos Al Transporte Público Urbano De Santiago**. Tese (doutorado em Engenharia Industrial). Universidad de Chile. 2019. Disponível em: https://repositorio.uchile.cl/bitstream/handle/2250/171777/Evaluacion-economica-y-socia.--de-la-incorporacion-de-buses-electricos-al-transporte.pdf?sequence=1&isAllowed=y. Acesso em: junho de 2022.

[26] C40 CITIES. **Urban Nature Declaration**. 2021b. Disponível em: c40.org/declarations/urban-nature-declaration/. Acesso em: junho de 2022.

PREFEITURA DE CURITIBA. **Com a C40, Curitiba dá mais um passo para conter crise climática**. Notícias, 14 de julho de 2021. Disponível em: https://www.curitiba.pr.gov.br/noticias/com-a-c40-curitiba-da-mais-um--passo-para-conter-crise-climatica/59747. Acesso em: junho de 2022.

[27] E-BUS RADAR. **Plataforma de ônibus elétricos na América Latina**. Desenvolvido pelo LABMOB-UFRJ, em parceria com Zebra, C40, ICCT. 2021. Disponível em: http://ebusradar.org. Acesso em: junho de 2022.

[28] PLATAFORMA NACIONAL DE MOBILIDADE ELÉTRICA (PNME). **Cenários de Eletrificação do Transporte Público no Brasil**. Webinário, 16 de dezembro. 2021. Disponível em: https://www.youtube.com/watch?v=-9fwPBKksjQk. Acesso em: junho de 2022.

[29] SOUZA LIMA, G. *et al.* Mobilidade elétrica: o ônibus elétrico aplicado ao transporte público no Brasil. **Revista dos Transportes Públicos,** ANTP, ano 41, 2° quadrimestre. 2019.

WRI BRASIL. **As barreiras a serem superadas para que os ônibus elétricos transformem as cidades**. Blogpost, 27 de junho. 2019. Disponível em: https://wribrasil.org.br/pt/blog/2019/06/barreiras-serem-superadas-para-que-os-onibus-eletricos-transformem-cidades. Acesso em: junho de 2022.29 SOUZA LIMA, G. *et al.* Mobilidade elétrica: o ônibus elétrico aplicado ao transporte público no Brasil. **Revista dos Transportes Públicos,** ANTP, ano 41, 2° quadrimestre. 2019.

[30] E-BUS RADAR. **Plataforma de ônibus elétricos na América Latina**. Desenvolvido pelo LABMOB-UFRJ, em parceria com Zebra, C40, ICCT. 2021. Disponível em: ebusradar.org. Acesso em: junho de 2022.

[31] SOUZA LIMA, G. *et al.* Mobilidade elétrica: o ônibus elétrico aplicado ao transporte público no Brasil. **Revista dos Transportes Públicos,** ANTP, ano 41, 2° quadrimestre. 2019.

[32] SOUZA LIMA, G. *et al.* Mobilidade elétrica: o ônibus elétrico aplicado ao transporte público no Brasil. **Revista dos Transportes Públicos,** ANTP, ano 41, 2° quadrimestre. 2019.

[33] MIT CLIMATE PORTAL. **How much CO2 is emitted by manufacturing batteries?** February 16, 2022. Disponível em: https://climate.mit.edu/ask-mit/how-much-co-2-emitted-manufacturing-batteries. Acesso em: junho de 2022.

[34] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT (2009). NBR ISO 14040: Avaliação do ciclo de vida - Princípios e estrutura. Disponível em: https://www.abntcatalogo.com.br/norma.aspx?ID=316462. Acesso em: junho de 2022.

[35] BRASIL (2010). Lei n.º 12.305, de 02 de agosto de 2010. Institui a Política Nacional de Resíduos Sólidos. Disponível em: http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm. Acesso em: junho de 2022.

[36] WORLD BANK (2019). GREEN YOUR BUS RIDE Clean Buses in Latin America. Report, 2019. Disponível em: https://documents1.worldbank.org/curated/en/410331548180859451/pdf/133929-WP-PUBLIC-P-164403-Summary-Report-Green-Your-Bus-Ride.pdf. Acesso em: 29 junho de 2022.

[37] MINISTÉRIO DE MINAS E ENERGIA; EMPRESA DE PESQUISA ENERGÉTICA. **2031: Plano decenal de energia**. Brasília: MME/EPE, 2022. Disponível em: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/Documents/PDE%202031_RevisaoPosCP_rvFinal.pdf. Acesso em: junho de 2022.

[38] CPFL ENERGIA S.A. **Projeto Emotive**. 2018. Disponível em: https://repositorio.enap.gov.br/handle/1/3622. Acesso em: junho de 2021.

[39] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[40] AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA (ANEEL). **Perguntas frequentas sobre Tarifa Branca. Ministério de Minas e Energia**, 2022. Disponível em: https://www.gov.br/aneel/pt-br/assuntos/tarifas/tarifa-branca/perguntas-frequentes-sobre-tarifa-branca. Acesso em: junho de 2022.

[41] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen--how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[42] CARVALHO, C. H. R. Emissões relativas de poluentes do transporte motorizado de passageiros nos grandes centros urbanos brasileiros. **Texto para Discussão**, n.º 1606, Brasília, Instituto de Pesquisa Econômica Aplicada (Ipea). 2011. Disponível em: https://www.econstor.eu/bitstream/10419/91332/1/664398472.pdf. Acesso em: junho de 2022.

[43] TAKANO, A. P. C. *et al.* Pleural anthracosis as an indicator of lifetime exposure to urban air pollution: An autopsy-based study in Sao Paulo. **Environmental Research**, 173, 23–32, 2019.

[44] TAKANO, A. P. C. *et al.* Pleural anthracosis as an indicator of lifetime exposure to urban air pollution: An autopsy-based study in Sao Paulo. **Environmental Research**, 173, 23–32, 2019.

[45] ALDEIA, G. L. *et al.* Poluição sonora: uma ameaça à saúde? **Revista Saúde e Meio Ambiente – RESMA**, Três Lagoas, v. 9, n.3, p. 34-40, agosto/dezembro. 2019.

[46] BORÉN, S. *et al.* Preferences of Electric Buses in public Transport; Conclusions from Real Life Testing in Eight Swedish Municipalities. **International Journal of Environmental and Ecological Engineering**, 10(3), pp. 259–268. 2016. Disponível em: https://publications.waset.org/10003929/pdf. Acesso em: junho de 2022.

GODÍNEZ-ZAMORA, G. *et al.* Decarbonising the transport and energy sectors: Technical feasibility and socioeconomic impacts in Costa Rica. **Energy Strategy Reviews**, 32. 2020. Disponível em: https://doi.org/10.1016/j.esr.2020.100573. Acesso em: junho de 2022.

KWON, Y. *et al.* What attributes do passengers value in electrified buses? **Energies**, 13(10), pp. 1–14. 2020. Disponível em: https://doi.org/10.3390/en13102646. Acesso em: junho de 2022.46 BORÉN, S. *et al.* Preferences of Electric Buses in public Transport; Conclusions from Real Life Testing in Eight Swedish Municipalities. **International Journal of Environmental and Ecological Engineering**, 10(3), pp. 259–268. 2016. Disponível em: https://publications.waset.org/10003929/pdf. Acesso em: junho de 2022.

[47] TFL. Transport for London to trial innovative new bus sound to improve road. Notícia, 18 de dezembro. 2019. Disponível em: https://tfl.gov.uk/info-for/media/press-releases/2019/december/tfl-to-trial-innovative-new-bus-sound-to-improve-road-safety. Acesso em: junho de 2022.

[48] BORÉN, S. *et al.* Preferences of Electric Buses in public Transport; Conclusions from Real Life Testing in Eight Swedish Municipalities. **International Journal of Environmental and Ecological Engineering**, 10(3), pp. 259–268. 2016. Disponível em: https://publications.waset.org/10003929/pdf. Acesso em: junho de 2022.

GODÍNEZ-ZAMORA, G. *et al.* Decarbonising the transport and energy sectors: Technical feasibility and socioeconomic impacts in Costa Rica. **Energy Strategy Reviews**, 32. 2020. Disponível em: https://doi.org/10.1016/j.esr.2020.100573. Acesso em: junho de 2022.

KWON, Y. *et al.* What attributes do passengers value in electrified buses? **Energies**, 13(10), pp. 1–14. 2020. Disponível em: https://doi.org/10.3390/en13102646. Acesso em: junho de 2022.48 BORÉN, S. *et al.* Preferences of Electric Buses in public Transport; Conclusions from Real Life Testing in Eight Swedish Municipalities. **International Journal of Environmental and Ecological Engineering**, 10(3), pp. 259–268. 2016. Disponível em: https://publications.waset.org/10003929/pdf. Acesso em: junho de 2022.

[49] BRASIL. **Entenda como a matriz elétrica brasileira está mudando**. Governo do Brasil, 30 de agosto. 2021. Disponível em: https://www.gov.br/pt-br/noticias/energia-minerais-e-combustiveis/2021/08/entenda-como-a-matriz-eletrica-brasileira-esta-mudando. Acesso em: junho de 2022.

[50] MIT CLIMATE PORTAL. **How much CO2 is emitted by manufacturing batteries?** February 16, 2022. Disponível em: https://climate.mit.edu/ask-mit/how-much-co2-emitted-manufacturing-batteries. Acesso em: junho de 2022.

THE GUARDIAN. **Child labour, toxic leaks: the price we could pay for a greener future**. Jan 3, 2021. Disponível em: https://www.theguardian.com/environment/2021/jan/03/child-labour-toxic-leaks-the-price-we-could-pay-for-a-greener-future. Acesso em: junho de 2022. 50 MIT CLIMATE PORTAL. **How much CO2 is emitted by manufacturing batteries?** February 16, 2022. Disponível em: https://climate.mit.edu/ask-mit/how-much-co2-emitted-manufacturing-batteries. Acesso em: junho de 2022.

[51] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[52] BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID); MINISTÉRIO DO DESENVOLVIMENTO REGIONAL (MDR). **Guia de eletromobilidade.** Orientações para estruturação de projetos no transporte coletivo por ônibus. Brasília, 2022. Acesso em: junho de 2022.

[53] GRAMKOW, C.; MAGACHO, G. “O verde nas medidas para recuperação da economia nos EUA e reflexões para o Brasil”.In: RONCAGLIA, A.; BARBOSA, N. (orgs). **Bidenomics nos trópicos**. Rio de Janeiro: FGV Editora, 2021. 286p. ePub. alks, 2020. Disponível em: https://www.ted.com/talks/david_lammy_climate_justice_can_t_happen_without_racial_justice. Acesso em: junho de 2022.

LANE, H. *et al.* Historical Redlining Is Associated with Present-Day Air Pollution Disparities in U.S. Cities. **Environ. Sci. Technol. Lett**, 9, 4, 345–350, 2022.53

[54] LANDRIGAN, P. J. *et al.* Environmental Justice and the Health of Children. **Mt Sinai J Med**., Mar-Apr; 77(2): 178–187, 2010.

LAMMY, D. **Climate justice can't happen without racial justice**. TED Talks, 2020. Disponível em: https://www.ted.com/talks/david_lammy_climate_justice_can_t_happen_without_racial_justice. Acesso em: junho de 2022.

UN ENVIRONMENT. **Global Environment Outlook - GEO-6:** Healthy Planet, Healthy People. Nairobi, 2019.

BOARETO, R. Política De Mobilidade Urbana transforma das cidades. **E-metropolis**, n. 44, p. 123–132, 2021.54 LANDRIGAN, P. J. *et al.* Environmental Justice and the Health of Children. **Mt Sinai J Med**., Mar-Apr; 77(2): 178–187, 2010.

[55] LANDRIGAN, P. J. *et al.* Environmental Justice and the Health of Children. **Mt Sinai J Med**., Mar-Apr; 77(2): 178–187, 2010.

LAMMY, D. **Climate justice can't happen without racial justice**. TED Talks, 2020. Disponível em: https://www.ted.com/talks/david_lammy_climate_justice_can_t_happen_without_racial_justice. Acesso em: junho de 2022.

UN ENVIRONMENT. **Global Environment Outlook - GEO-6:** Healthy Planet, Healthy People. Nairobi, 2019. 55 LANDRIGAN, P. J. *et al.* Environmental Justice and the Health of Children. **Mt Sinai J Med**., Mar-Apr; 77(2): 178–187, 2010.

BOARETO, R. Política De Mobilidade Urbana transforma das cidades. **E-metropolis**, n. 44, p. 123–132, 2021.

[56] GÊNERO NÚMERO. **Maioria no transporte público, mulheres estão à margem das políticas de mobilidade**. Reportagem, 9 de março. 2017. Disponível em: https://www.generonumero.media/maioria-no-transporte-publico-mulheres-estao-a-margem-das-politicas-de-mobilidade/. Acesso em: junho de 2022.

[57] SPTRANS. **Pesquisa da SPTrans aponta que mulheres são maioria dos passageiros de ônibus e que fazem menos teletrabalho**. Secretaria Especial de Comunicação da cidade de São Paulo, 26 de maio. 2021. Disponível em: https://www.capital.sp.gov.br/noticia/pesquisa-da-sptrans-aponta-que-mulheres-sao-maioria-dos-passageiros-de-onibus-e-que-fazem-menos-teletrabalho. Acesso em: junho de 2022.

[58] Dados compilados pelos indicadores da plataforma MobiliDADOS, idealizada e gerenciada pelo ITDP Brasil. Disponível em: https://mobilidados.org.br/.

[59] CONFEDERAÇÃO NACIONAL DO TRANSPORTE (CNT). **Painel CNT do Transporte — Rodoviário**. 2021. Disponível em: https://www.cnt.org.br/painel-cnt-transporte-rodoviario. Acesso em: junho de 2022.

[60] MEDEIROS, A. M. **Perda auditiva em trabalhadores do transporte urbano na Região Metropolitana de Belo Horizonte, Minas Gerais, Brasil.** Artigo. Universidade Federal de Minas Gerais. Disponível em: https://doi.org/10.1590/0102-311X00132314 . Acesso em: junho de 2022.

[61] GRAMKOW, C.; MAGACHO, G. "O verde nas medidas para recuperação da economia nos EUA e reflexões para o Brasil".In: RONCAGLIA, A.; BARBOSA, N. (orgs). **Bidenomics nos trópicos**. Rio de Janeiro: FGV Editora, 2021. 286p. ePub.

[62] CARVALHO, R. P. L. **Tarifa comercial zero em Volta Redonda**: a mobilidade urbana e a interligação dos centros comerciais através do ônibus elétrico. Monografia (graduação em Administração). Universidade Federal Fluminense, Niterói, RJ. 2020.

[63] PREFEITURA DE VOLTA REDONDA. **Tarifa comercial zero contará com três ônibus elétricos até o final de setembro**. Notícias, 14 de agosto de 2019. Disponível em: https://www.voltaredonda.rj.gov.br/cidade/31-noticias-em-destaque/smdet/1642-tarifa-comercial-zero--contar%C3%A1-com-tr%C3%AAs-%C3%B4nibus-el%-C3%A9trico-at%C3%A9-o-final-de-setembro/. Acesso em: junho de 2022.

[64] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen--how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[65] SLOWICK, P. *et al*. **Avaliação Internacional de Políticas Públicas para Eletromobilidade em Frotas Urbanas. Relatório** (PROMOB-E). Brasília: Ministério da Indústria, Comércio Exterior e Serviços; GIZ. 2018. Disponível em: https://theicct.org/publication/avaliacao-internacional--de-politicas-publicas-para-eletromobilidade-em-frotas-urbanas/. Acesso em: junho de 2022.

[66] SLOWICK, P. *et al*. **Avaliação Internacional de Políticas Públicas para Eletromobilidade em Frotas Urbanas. Relatório** (PROMOB-E). Brasília: Ministério da Indústria, Comércio Exterior e Serviços; GIZ. 2018. Disponível em: https://theicct.org/publication/avaliacao-internacional--de-politicas-publicas-para-eletromobilidade-em-frotas-urbanas/. Acesso em: junho de 2022.

[67] SLOWICK, P. *et al*. **Avaliação Internacional de Políticas Públicas para Eletromobilidade em Frotas Urbanas. Relatório** (PROMOB-E). Brasília: Ministério da Indústria, Comércio Exterior e Serviços; GIZ. 2018. Disponível em: https://theicct.org/publication/avaliacao-internacional--de-politicas-publicas-para-eletromobilidade-em-frotas-urbanas/. Acesso em: junho de 2022.

[68] SLOWICK, P. *et al.* **Avaliação Internacional de Políticas Públicas para Eletromobilidade em Frotas Urbanas. Relatório** (PROMOB-E). Brasília: Ministério da Indústria, Comércio Exterior e Serviços; GIZ. 2018. Disponível em: https://theicct.org/publication/avaliacao-internacional--de-politicas-publicas-para-eletromobilidade-em-frotas-urbanas/. Acesso em: junho de 2022.

[69] C40 CITIES; WRI. **Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2**. Relatório. 2018. Disponível em: https://www.transformative-mobility.org/publications/electric-buses-in-cities-driving--towards-cleaner-air-and-lower-co2. Acesso em: junho de 2022.

[70] BLOOMBERG. **Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite**. News, November 30, 2011. Disponível em: https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start--to-bite/. Acesso em junho de 2022.

[71] IEMA. **Análise de aspectos fundamentais para a introdução de ônibus não poluentes em 13 cidades brasileiras**. 2020b. Disponível em: http://energiaeambiente.org.br/produto/analise-de-aspectos-fundamentais-para-a-introdução-de-onibus-nao-poluentes-em-13-cidades-brasileiras. Acesso em: junho de 2022.

[72] BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID); MINISTÉRIO DO DESENVOLVIMENTO REGIONAL (MDR). **Gestão da demanda de mobilidade**. Global Environment Facility – GEF (financiador). Brasília: Editora IABS, 2020.

[73] WRI BRASIL. **As barreiras a serem superadas para que os ônibus elétricos transformem as cidades**. Blogpost, 27 de junho. 2019. Disponível em: https://wribrasil.org.br/pt/blog/2019/06/barreiras-serem-superadas-para-que--os-onibus-eletricos-transformem-cidades. Acesso em: junho de 2022.

[74] CITY MONITOR. **London congestion charge has been a huge success**. It's time to change it. Article, September 2, 2021. Disponível em: https://citymonitor.ai/transport/london-congestion-charge-has-been-huge-success-it--s-time-change-it-3751. Acesso em: junho de 2022.

[75] WRI BRASIL. **Modelo de negócios para adoção de ônibus elétricos**. Apresentação. E-mob, Brasília, DF, 9 de maio. 2018. Disponível em: https://antigo.mdr.gov.br/images/stories/ArquivosSEMOB/ArquivosPDF/eficiencia/eletromobilidade/Modelodenegociosparaadocao-deonibuseletricos.pdf. Acesso em: junho de 2022.

[76] Governo do Estado de São Paulo, Secretaria dos Transportes Metropolitanos, "Concorrência Internacional nº 004/2013, Processo STM Nº 000770/2012 - PPP da LINHA 6– Laranja"; e Governo do Estado da Bahia, Secretaria de Desenvolvimento Urbano, Edital Nº 01/2013, "Parceria público Privada na Modalidade de Concessão Patrocinada para implantação das obras civis e sistemas, fornecimento de material rodante, operação, manutenção e expansão do Sistema Metroviário de Salvador e Lauro de Freitas".

[77] ITDP BRASIL. **O papel da regulamentação na transição para eletromobilidade**. Blogpost, 29 de junho. 2020b. Disponível em: https://itdpbrasil.org/o-papel-da--regulamentacao-na-transicao-para-eletromobilidade. Acesso em: junho de 2022.

[78] WRI BRASIL. **Contratos de concessão de Bogotá e Santiago são inspiração para transporte coletivo no Brasil**. Blogpost, 16 de novembro. 2020a. Disponível em: https://wribrasil.org.br/pt/blog/cidades/mobilidade--urbana/contratos-concessao-bogota-santiago-inspiracao-transporte-coletivo-brasil. Acesso em: junho de 2022.

[79] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen--how-electric-buses-are-moving-cities/Acesso em: junho de 2022.

[80] WRI BRASIL. **Contratos de concessão de Bogotá e Santiago são inspiração para transporte coletivo no Brasil**. Blogpost, 16 de novembro. 2020a. Disponível em: https://wribrasil.org.br/pt/blog/cidades/mobilidade-urbana/contratos-concessao-bogota-santiago-inspiracao-transporte-coletivo-brasil. Acesso em: junho de 2022.

[81] DIRECTORIO DE TRANSPORTE PUBLICO METROPOLITANO (DTPM). **Website**. Disponível em: https://www.dtpm.cl/. Acesso em: junho de 2022.

[82] WRI BRASIL. **Contratos de concessão de Bogotá e Santiago são inspiração para transporte coletivo no Brasil**. Blogpost, 16 de novembro. 2020a. Disponível em: https://wribrasil.org.br/pt/blog/cidades/mobilidade-urbana/contratos-concessao-bogota-santiago-inspiracao-transporte-coletivo-brasil. Acesso em: junho de 2022.

[83] UNICAMP. **Ônibus elétrico começa a circular na Unicamp**. Campinas, São Paulo, 15 de setembro. 2020. Disponível em: https://www.unicamp.br/unicamp/noticias/2020/09/15/onibus-eletrico-comeca-circular-na-unicamp. Acesso em: junho de 2022.

[84] ITDP Brasil. **Incentivos na regulamentação podem ser chave para eletrificação**. 2020a. Disponível em: https://itdpbrasil.org/infografico-incentivos-na-regulamentacao-podem-ser-a-chave-para-a-eletrificacao/. Acesso em: junho de 2022.

[85] BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID); MINISTÉRIO DO DESENVOLVIMENTO REGIONAL (MDR). **Guia de eletromobilidade.** Orientações para estruturação de projetos no transporte coletivo por ônibus. Brasília, 2022.

[86] BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID); MINISTÉRIO DO DESENVOLVIMENTO REGIONAL (MDR). **Guia de eletromobilidade.** Orientações para estruturação de projetos no transporte coletivo por ônibus. Brasília, 2022.

[87] ALMEIDA, N. D. V. *et al.* As relações de gênero e as percepções dos/das motoristas no âmbito do sistema de trânsito. **Psicologia: Ciência e Profissão**, 25(2), junho. 2005. Disponível em: https://www.scielo.br/j/pcp/a/7HKfLVKNdYcSXMgpNfd6xZd/?lang=pt. Acesso em: junho de 2022.

[88] GOBIERNO DE CHILE (2018). **Agenda para la Política de Equidad de Género en Transportes.** Ministerio de Transportes y Telecomunicaciones. 2018-2022. Disponível em: https://www.subtrans.gob.cl/wp-content/uploads/2018/11/Agenda-PEGT-2018-2022.pdf. Acesso em: junho de 2022.

BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID). Transport Gender Lab (TGL). **Género y Transporte: Bogotá**. Disponível em: http://dx.doi.org/10.18235/0001388. Acesso em: junho de 2022.

[89] BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID). Transport Gender Lab (TGL). Disponível em: https://tglab.iadb.org/

BANCO INTERAMERICANO DE DESENVOLVIMENTO (BID). Transport Gender Lab (TGL). **Género y Transporte: Bogotá**. Disponível em: http://dx.doi.org/10.18235/0001388. Acesso em: junho de 2022.

[90] ITDP. **From Santiago to Shenzhen**: How Electric Buses are Moving Cities. Relatório. 2021. Disponível em: https://www.itdp.org/publication/from-santiago-to-shenzhen-how-electric-buses-are-moving-cities./Acesso em: junho de 2022.

[91] ITDP. Transport Emissions Evaluation Models for Projects (TEEMP). Disponível em: https://www.itdp.org/2012/08/06/transport-emissions-evaluation-model-for-projects-teemp-brt/. Acesso em: junho de 2022.

[92] IEMA. PlanFrota: ferramenta para transporte limpo. Disponível em: http://energiaeambiente.org.br/wp-content/uploads/2020/02/20200602_planfrotanosite.xlsx. Acesso em: junho de 2022.

[93] EPE. Guia de Usuário do Simulador para Avaliação de Viabilidade de Ônibus Elétrico. Disponível em: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/simulador-para-avaliacao-de-viabilidade-de-onibus-eletrico. Acesso em: junho de 2022.

[94] WRI. ImpactAr. Disponível em: https://wribrasil.org.br/pt/publicacoes/impactar-ferramenta-valoracao-impactos-qualidade-do-ar-saude-onibus-eletricos. Acesso em: junho de 2022.

[95] GREET. Greenhouse Gases, Regulated Emissions, and Energy Use. Disponível em: https://greet.es.anl.gov/. Acesso em: junho de 2022.

[96] E-BUS RADAR. **Plataforma de ônibus elétricos na América Latina**. Desenvolvido pelo LABMOB-UFRJ, em parceria com Zebra, C40, ICCT. 2021. Disponível em: http://ebusradar.org. Acesso em: junho de 2022.

[97] UNEP. The The eMob Calculator. Disponível em: https://www.unep.org/resources/toolkits-manuals-and-guides/emob-calculator. Acesso em: junho de 2022.

[98] HVIP. Total Cost of Ownership Estimator. Disponível em: https://californiahvip.org/. Acesso em: junho de 2022.

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