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Regulatory Challenges in the Electromobility Sector: An Analysis of Electric Buses in Brazil

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Abstract: In recent years, fleet electrification has become a viable alternative for reducing carbon emissions through laws and government incentives around the world. Not only that, such incentives have favored the development of new technologies for the sector that have resulted in the reduction of the manufacturing cost of electric vehicles, which in turn, enabled new business models favoring the evolution of the electromobility sector. However, Brazil has also shown itself to be a market on the rise. However, electromobility in Brazil is still at an early stage of development when compared to other countries. In this sense, this paper sought to present the current state of the Brazilian sector through existing laws, regulations and incentives. In addition, it discusses and proposes alternatives for the development and maturation of the sector. Finally, technical aspects related to the standardization of communication protocols and charger installations are also presented.

Keywords: electric bus; regulation; Brazilian electromobility; overview

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1. Introduction

The transportation sector is one of the most-dependent on the use of fossil fuels, whose combustion is responsible for the emission of carbon dioxide (CO_2), as well as other greenhouse gases (GHGs) [1]. In the global panorama, for the year 2021, road transport was responsible for approximately 16% of total CO_2 emissions [2]. In the Brazilian scenario, for the same year, about 46% of total CO_2 emissions in the country were caused by land transport, of which 53% were related to passenger transport (including buses) [3]. Otherwise, if only buses and trucks (heavy vehicles) were considered, a proportion of 57% of the total CO_2 emissions related to road transport in the country was reached [3].In this context, electrification has emerged as the leading option to achieve the decarbonization of land transport [1], predominantly driven by the light vehicle sector. However, in recent years, this scenario has been changing, given the growth of heavy-duty vehicles' share in the carbon-free market. Thus, batteries and hydrogen have emerged as the two main technologies for the decarbonization of the segment, due to the commercialization of battery electric vehicles (BEVs) and hydrogen fuel cell vehicles (HFCVs) [4]. Fuel cell and battery vehicles both use electric motor propulsion, sharing a variety of components, including the same electric motors [1,4]. The main difference lies in the fact that batteries store energy in electrochemical form, while fuel cells produce onboard electricity in an electrochemical process that extracts electrons from hydrogen by combining it with oxygen from the air [4].

In this sense, several aspects catalyzed electrification. These include increasingly stringent regulations, with increasingly stricter CO_2 emission standards in most parts of the world, as well as high incentives for the sale of electric vehicles (EVs). In addition, automakers have been expanding the offer of EVs, with the announcement of, e.g., more than 400 electric and plug-in hybrid models by 2025. In the same vein, it is important to emphasize the role of investors, consumers, partners, and society itself in exerting pressure for the decarbonization of transportation [5]. All these efforts are motivated by the numerous advantages that the electrification of heavy transport provides; among them can be mentioned: improved torque, reduced maintenance requirements, reduced environmental noise, and reduced total cost of ownership (TCO).

Instant torque or the ability to deliver maximum torque at zero revolutions per minute (RPM) is a unique feature of electric trucks. This allows these vehicles to tow and carry a large payload at much lower speeds than conventional vehicles [6].

Another advantage of heavy EVs is the reduced need for maintenance activities [7,8]. Although they do require some scheduled maintenance for their electrical systems, the activities are minimal compared to those required for combustion vehicles. This fact results from the EV having a smaller amount of moving parts than a combustion engine, and it also does not have any oil or transmission fluid to replace. In BEVs' case, the brake systems also last longer than conventional vehicles, thanks to their regenerative braking systems. These systems use the EV engine as a generator to convert much of the kinetic energy lost during deceleration into energy stored in the vehicle's battery. The net effect is that there is substantially less wear on the brakes and the pads last considerably longer than those on conventional vehicles. Thereby, reduced maintenance activities lead to less downtime for heavy EVs, enabling higher utilization rates and lowering the TCO of the entire fleet. Therefore, fewer backup vehicles are needed for emergency coverage and scheduled maintenance.

The reduction of environmental noise is another factor that is favorable for heavy EVs. Propulsion noise is considerably less without a combustion engine. This is most impactful when vehicles operate at low speeds, as is more often the case in urban areas, where noise pollution is a major concern. At low speeds, EVs can be up to 14 dB quieter than an equivalent combustion vehicle, making them more enjoyable for both the operator and users, as well as the neighborhood [9].

In terms of the annual operating costs of electric buses, it is estimated that they account for, on average, less than half of the costs of a diesel bus. These savings result in a lower TCO over the life of the vehicle. McKinsey consultancy forecasted that electric trucks and buses will reach TCO parity with diesel before 2025 [10].

In this context, it is emphasized that, in recent years, the number of heavy electric vehicles has been growing around the world, led by China, Europe, and the United States [11]. However, some barriers still exist and need to be addressed for the massive electrification of public transportation. In common terms, the high investment cost for the acquisition of battery electric buses (BEBs) and fuel cell electric buses (FCEBs) is one of the main obstacles, although for BEBs, it is expected that, by 2030, the cost will be similar to diesel buses, as the price of batteries will drop significantly [12]. On a technical aspect, the biggest challenges are related to the charging infrastructure for battery electric vehicles and its impact on the grid, as well as the production and infrastructure for refueling fuel cell vehicles [4,12,13].

Thus, among the obstacles to the penetration of battery electric vehicles in the mobility market, in general, is the lack of charging infrastructure to meet the growing demand of this niche [14]. As a consequence, the problem of the strategic geographic allocation of charging points emerges, taking into account the distance, capacity, and time for charging. In the same sense, the growth in the use of electric vehicles and their connection to the electrical system cause an increase in energy demand, which can cause security problems in the supply of electricity, especially during peak hours [15]. Another important factor concerns the limited autonomy of electric vehicle batteries compared to combustion vehicles. To overcome this limitation, bus fleet operators need to investigate which vehicle types and charging technologies are suitable for the different routes in their cities [12].

In the context of hydrogen, it is estimated that 80% of the world's industrial production comes from fossil fuels, including natural gas and nuclear energy [13]. Thus, the generation of hydrogen from fossil fuels occurs mostly with harmful emissions to the atmosphere [13]. As an alternative, the most-promising option is the implementation of green hydrogen technology, which is the obtaining of hydrogen from renewable energy sources, usually using an electrolyzer [13]. In terms of infrastructure, the number of refueling stations for fuel cell vehicles is still limited [16]. On the vehicle side, another problem found is related to the onboard storage of hydrogen. Such fuel is hazardous due to its low ignition energy and high combustion energy. Once the supply structure of the system is damaged, hydrogen leakage can occur, which could cause environmental problems, a possible insufficiency in supply for propulsion, and fires, endangering the safety of people and property [17]. Thus, a robust and reliable supply system is essential for the normal operation of a fuel cell vehicle [17].

In the Brazilian panorama, the development of the hydrogen-related industry is at an even more incipient stage. In December 2022, EDP Brazil produced the first green hydrogen molecule at an industrial level, representing an important step for the sector, but evidencing the embryonic stage of maturity of the technology in the country. The first hydrogen bus in Brazil with totally national technology was released in 2010, developed by the Alberto Luiz Coimbra Institute for Postgraduate and Engineering Research, Federal University of Rio de Janeiro (Coppe-UFRJ) [18]. In early 2022, a group of eight companies in partnership with Coppe-UFRJ initiated the manufacturing of a new prototype on a pre-industrial scale [19]. However, there is no commercialization of any fuel cell vehicle model in the country, as well as no implementation of infrastructure for refueling. In view of this, and taking into account the R&D project that originated this study, the authors addressed, in the scope of this article, only the electrification of fleets by means of battery electric vehicles.

In the global scenario, most countries recognize the important role of the transport sector to reduce GHG emissions, including the modernization of transport in their national plans. In Portugal, for example, the current bus fleet, mostly composed of fossil fuel vehicles, has been developed in order to become more sustainable in the near future [1]. Thus, efforts have been applied in the country, using the shift of the current fleet to electric vehicles as a way to achieve zero-carbon public transport [1]. By 2021, 55 of the buses running in Portugal were electric, with the perspective of investments in the sector to achieve full fleet electrification by 2034 [1]. China, meanwhile, has achieved large-scale electrification of its urban buses, having 98% of the global electric bus inventory [20]. As one of its greatest examples is Shenzen, which became, worldwide, in the year 2017, the first city to have a fully electrified urban bus fleet, with 16359 electric buses [20]. In addition, private cars, garbage trucks, and other heavy vehicles are also moving towards electrification in the city [20].

In Brazil, bus fleet electrification has been gradually developed. As an example, the city of São Paulo, one of the main metropolises in the country, approved in 2018 a municipal law establishing the goal of reducing CO_2 emissions from public transport by at least 50% by 2028 and 100% by 2038. As a consequence, in the year 2023, it is expected that the city will have more than 650 electric buses in its fleet. In an assessment conducted in December 2022, the total number of electric vehicles in public transport was 386 (Figure 1), of which 219 were part of the fleet in the city of São Paulo [21].

In the overall context of electromobility, Brazil had 131,007 electric vehicles at the end of January 2023 [22]. Furthermore, at the end of 2022, the share of electric and hybrid vehicles in sales was 2.5% [23]. However, it is estimated that, in 2030, they will represent between 12% and 22% of registrations in Brazil, or even between 32% and 62%, depending on the regulatory path that the country will follow. In terms of charging infrastructures for electric vehicles, the country has experienced the increasing implementation of charging stations and electric corridors in the national territory, such as the Green Corridor [24], which connects six northeastern states, the Eletroposto Celesc project [25], which aims to cover the entire state of Santa Catarina, and the Rio-São Paulo electric corridor, responsible for interconnecting the states of Rio de Janeiro and São Paulo, among others.

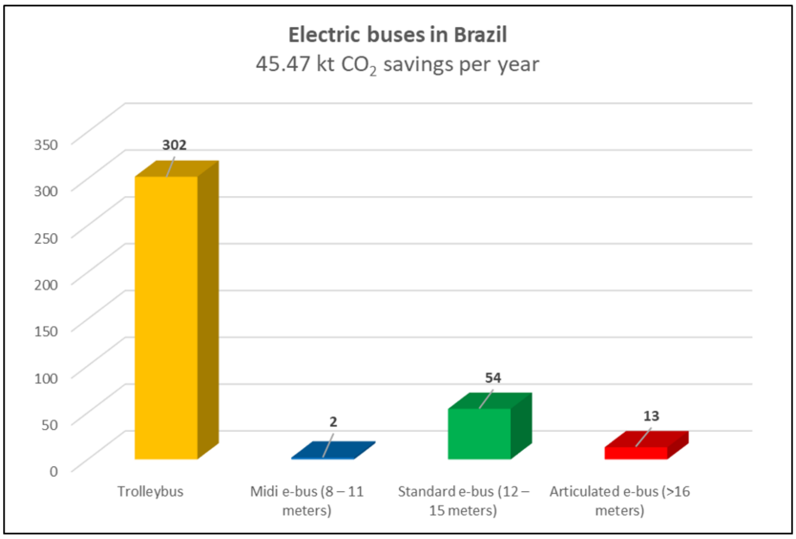


Figure 1. Electric buses in Brazil according to [21]. Data from February 2023.

In this context, the evolution of electromobility in the Brazilian panorama is evident. On the other hand, such a development has not been accompanied by national regulations. A lack of standardization and regulatory frameworks and the absence of new business models, access to credit, and the general knowledge of the population about the benefits of electrification are factors that have restricted the electric mobility market in the country [26]. The problem is further compounded due to the lack of awareness, interest, and involvement of local authorities, not providing public policies such as incentives for the development of the national industry and technology. The absence of a national electric vehicle industry implies that battery vehicles cost up to three-times that of combustion vehicles [26]. Besides the aspects of encouraging the national industry and the acquisition of electric vehicles, as well as the expansion of charging infrastructures, regulatory issues and standards for the integration of the electric vehicle with the grid need to be discussed, such as the communication protocols between electric vehicle, charging stations, charging station operators, system operators, and electric power companies [27].

In view of the presented challenges, the main contribution of this article is the presentation of an overview of the current scenario of electric mobility in Brazil in terms of public policies, regulations, and government incentives, and based on this, we discuss and propose alternatives to foster the development of the sector. As a relevant factor, the several challenges encountered during the development of the project that originated this article were taken into consideration, such as finding ways to financially enable new businesses, integration problems between the electric vehicle and the charging station, and alternatives for reducing the impact to the electric grid, among others, contributing significantly to the proposals presented. In this sense, this article was the result of an R&D project that aimed to develop new business models for the Brazilian electric mobility sector, focusing on the electrification of public transportation.

The paper is organized as follows: Section 2 presents the R&D project that originated this article, addressing the main agents involved, the objectives of the development, and the contribution of such points for the study of fleet electrification; Section 3 presents an overview of the international scenario of electric mobility with a focus on the electrification of bus fleets, discussing the main public policies and incentives that have supported the sector in the reference countries. In the Brazilian context, given the development in a more attenuated way, the main bills still in progress are presented, as well as the existing public policies that aim to support electric mobility. Section 4 presents the regulatory proposals for the promotion of electromobility in Brazil, presenting alternative initiatives to be adopted in the various subsectors. Finally, Section 5 gives the final discussions.

2. R&D Project—Electric Bus

The electromobility sector has been gaining space over the years as a decarbonization pathway for transportation. The transportation sector, specifically the electrification of bus fleets, has a great potential for socio-environmental and financial return, providing new opportunities also for the electricity sector. However, in Brazil, despite the accelerated growth of electromobility, there are barriers that impact the healthy development of this sector such as a lack of adequate charging infrastructure and public policies [14,26].

Regarding the lack of adequate infrastructure, few regions of Brazil have enough public charging stations to promote the adoption of electric vehicles, and they are concentrated in the south and southeast states. The remaining states located in the north and northeast still have few or no public charging stations available [28]. Despite that, another important factor to be considered is the impact of charging stations on the grid. Several studies have been conducted in Brazil, mainly funded by the ANEEL R&D program, in order to mitigate or forecast the grid impacts of charging stations by using energy storage systems for demand side management [29], implementing smart controllers with distributed energy resources (DERs) [30], using vehicle-to-grid (V2G) strategies to reduce peak demand [31], or conducting forecasts to provide subsidies for a better expansion of charging infrastructure [28,32]. In addition, the R&D project presented in the following also conducted research on this topic and proposed a smart dynamic control charging to avoid grid capacity overload due to EV charging, as presented in [33].

In this context, the Brazilian R&D project named "Development and Pilot Implementation of a Technical and Business Model of Recharge Infrastructure for Electric Bus Fleets" is an initiative of EDP Brasil and the CERTI Foundation as part of the ANEEL R&D program, with the objective of promoting bus electrification in parallel with the expansion of charging infrastructure, but also analyzing the barriers and proposing solutions for electromobility's sustainable growth, which is the subject that originated this paper.

The main goals of the project were as follows:

- Provide the state-of-the-art regarding the electromobility sector considering new technologies, business models, financial incentives, and regulations in Brazil;
- Acquire an electric bus to validate the developments inside the project such as the methodology of charging infrastructure expansion, business models, and data acquisition of bus and charging stations;
- Expand the charging infrastructure in an optimized way for electric bus use;
- Establish partnerships with the electric bus and charging station industries to boost the Brazilian market;
- Study the impact of the penetration of charging stations into the electricity grid and proposals for mitigating the effects [33];
- Propose a new business model for EDP Brasil for future investments in this sector [34].

The project delivered a new charging infrastructure in the state of Espírito Santo focusing on optimizing the use of electric buses. The chosen locations for installing each one of the charging stations were defined by a study that correlated the battery degradation of the bus with the demand for routes for passenger transportation in the region. The infrastructure has an extent of 150 km, and it is presented in Figure 2. The charging infrastructure is composed of four AC charging stations with the following technical specifications:

- **Model:** WEG Wemob Parking;
- **Power supply:** 380 VAC (3P + N), 60 Hz;
- **AC output:** 2 × 44 kVA (64 A), 380 VAC (3P + N);
- **Connector:** Type 2;
- **Communication:** OCPP 1.6 J.

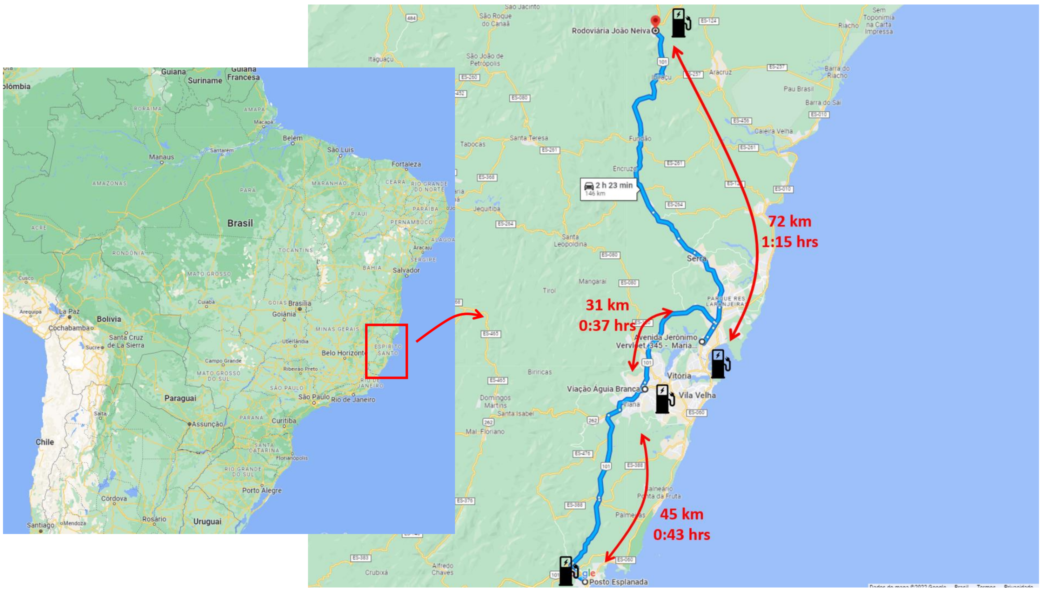


Figure 2. Charging infrastructure implemented in Espírito Santo during the R&D project.

The electric bus in the project was acquired in partnership with a logistic company of the region. In addition, a monitoring system was installed on the bus to collect essential data (e.g., real-time location, state of charge (SoC), speed, acceleration, autonomy) to assist the development and prove the final results of the business model in this project. The technical specifications of the bus are presented below:

- **Model:** BYD D9F;
- **Autonomy:** 400 km;
- **Time of charge:** 4–5 h (0% to 100%);
- **Battery:** BYD LiFePO4, 324 kWh;
- **Charging:** 2 × 40 kW (AC Type 2).

The charging infrastructure and the electric bus are presented in Figure 3.

(a) (b)

Figure 3. (**a**) Electric bus. (**b**) Charging station.

Additionally, the project's deliverable was an economic and technical viability study that will be used as a reference to guide future EDP Brasil investments in this sector. The study was based on the data obtained during the project, e.g., electric bus and charging station use, feedback from the partner logistic company, and the investments executed for the installation and maintenance of the infrastructure [34].

Therefore, in this context, the following sections will approach the current Brazilian regulatory scenario regarding the electromobility sector, proposing ways to incentivize the evolution of this sector, through the improvement of regulations, financial programs, and technical specifications and promoting new business models.

3. Electromobility Overview

For a broader view of the current scenario in Brazil and in the world, a survey on the status of electric buses currently, as well as the incentive policies in force in the countries that use this means of transport the most was carried out and presented in this section.

3.1. International Scenario

At the end of 2020, there were 600,000 electric buses running around the world [10], representing 39% of new sales and 16% of the global fleet by that year. Two years later, this number showed considerable growth. The global market for electric buses reached USD 19.2 billion in 2022 [35]. Yet, some researches expect a compound annual growth rate (CAGR) of 20.2% during the forecast period of 2021 to 2028, as seen in Figure 4.

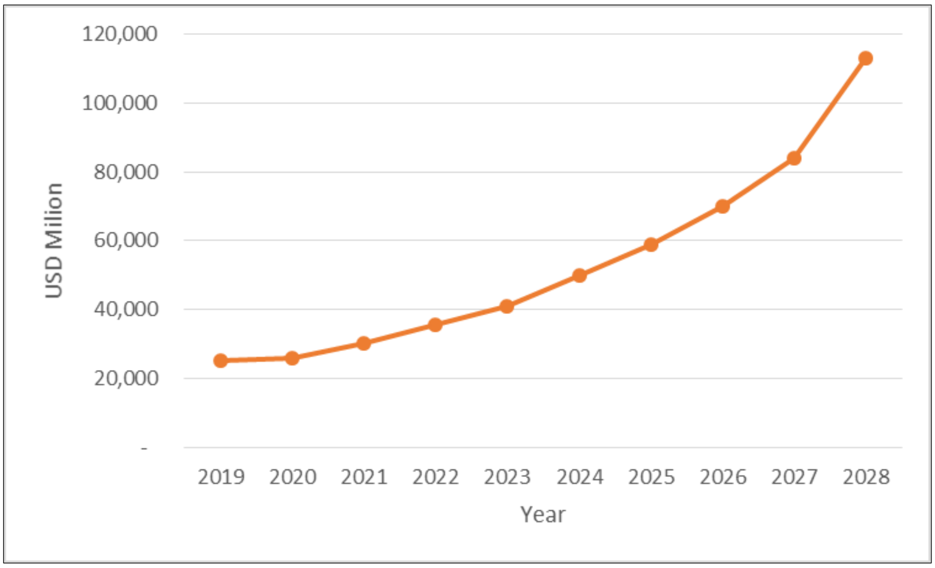


Figure 4. Value of global electric bus market, 2019–2028 [35].

The vast majority of all electric bus sales in 2020 were inChina. The country purchased more than 74,000 unitsand continues to represent 98% of the global electric bus fleet. However, this share started to decline as some Chinese city bus fleets started to become saturated and their adoption in Europe, North America, South Korea, Southeast Asia, India, and South America increased.

In 2025, sales of electric buses outside China are expected to reach 14,000, against the 5000 in 2020. According to the study, the biggest short-term opportunities to spread EVs in emerging economies are electric buses and electric motorcycles. This is explained by the mobility characteristics in these countries, where private electric cars are still inaccessible to the general population. In this context, public transport is widely used and has the potential to be modernized with electrification.

When it comes to other heavy vehicles, such as commercial trucks, the adoption of electric versions lags behind buses. The combination of more models available, corporate fleet contracts, favorable economics, tax incentives, public policy, and growing concern for urban air quality is set to tilt the commercial van and truck segment towards electrification in the coming years.

In this section, electric bus policies, norms, and incentives from countries where this technology is growing are presented. The main policies concerning electric buses are [36]:

- Public transportation policy: subsidies for electric fleets operation and quality of service improvement;
- Incentives: subsidies for purchasing, tax incentives, and subsidies for infrastructures;
- Regulations: zero-emission vehicle mandates, fuel economy standards, and charging infrastructure regulations;
- Industrial policy: subsidies for production.

3.1.1. China

China, as a manufacturer and exporter of EVs, as well as parts and components for assembly, also has government support and policies for the internal growth of this market. Due to the demographic characteristics of China, EVs, mainly for public transport, play a fundamental role in mobility plans, where the main objective is to control and reduce air pollution. To this end, China has measures to encourage the growth of the so-called new energy vehicles (NEVs), which include battery EVs, plug-in hybrid vehicles, and fuel cell vehicles.

In recent years, China's central government and local authorities have launched various supporting policies to boost the market's development, promote advanced industrial chains, create a skilled workforce, and achieve technological breakthroughs and efficiency gains in the field of bus battery technology. Support policies include subsidies for the buses' purchase and operation, as well as tax breaks and other incentives for withdrawing and decommissioning buses with conventional combustion engines. In [37], the "generous" government subsidy policy as the main driver for the rapid advance of fleet electrification was defined.

With the green revolution, China has the ambition to promote low carbon emissions, and the adoption of electromobility specifically in public transport has accelerated even more. Currently, the challenge is to expand the electric vehicle charging infrastructure and increase the overall efficiency of the system, to ensure that the growth of the electric vehicle market is sustainable in the medium to long term.

According to [38], some of the policies implemented in the context of NEV buses in recent years have been:

- Tax reductions: urban public transport buses receive a tax reduction, both on purchase and vehicle tax during the circulation time;
- Safety supervision: to ensure the safe operation of EVs in the public sector, telemetry information is supervised in real-time to help users use vehicles and spread the culture that EVs are safe;
- Local policies: subsidies for the acquisition of battery-powered buses for public transport in urban areas; incentives for expanding charging infrastructure; support for electric bus operators with supervision and security;
- Electrification of fleets in public service: replacement of combustion vehicles with EVs in the public service, mainly public transport buses.

Subsidies for electric buses usually do not consider hybrid buses, due to the high pollution factor of diesel. In this case, the contemplated buses are battery or fuel cell only. These incentives take into account the type of vehicle, size, technical indicators (consumption, battery density, power, etc.), and tax range.

Because of the implemented policies, the share of electric buses in China continues to grow, and the total fleet of clean energy buses (including battery and fuel cell buses) is roughly 98% of all the deployed electric buses in the world [36]. With the continuous government promotion of electromobility, incentive policies, and non-fiscal support measures, the adoption of buses continues to grow. In addition, with the popularization of battery technology and the resulting fall in prices, it is expected that these vehicles will become even more attractive, until government support is no longer needed to promote the market.

3.1.2. Europe

Among various initiatives for EV dissemination in Europe, the European Union's Clean Vehicles Directive stands out. It promotes non-polluting mobility solutions in public tenders, providing a solid boost to demand and the implementation of low- and zero-emission vehicles. The new directive defines "clean vehicles" and sets national targets for the respective public procurement. It applies to different means of public procurement, including purchase, lease, rent, and relevant service contracts.

The directive sets separate targets for light and heavy vehicles. In the context of heavy vehicles, the following are considered: any truck or bus using one of the following alternative fuels: hydrogen, battery electric (including plug-in hybrids), natural gas (both CNG and LNG, including biomethane), liquid biofuels, synthetic and paraffinic fuels, LPG [39].

Aiming at energy security, concerns about climate change, and the search for more innovation and industrial opportunities, over the last few years, there has been a strong performance of the European block in promoting the development of its electric mobility ecosystem [40]. In summary, the policies and directives adopted are divided into the following:

1. **Vehicle emission standards:** The 2020 emission targets have been extended to new cars (95 gCO_2/km) and new vans (147 gCO_2/km), and specific emission targets have been set for each manufacturers.
2. **Recharging infrastructure and vehicle targets:** Based on the EU Alternative Fuels Infrastructure Directive, the EU established that the Member States should set implementation targets for publicly accessible chargers for 2020 (mandatory), 2025, and 2030.
3. **Building construction regulations:** The revision of the Energy Performance Buildings Directive in 2018, which requires Member States to specify, by March 2021, the minimum requirements for charging infrastructure in new and renovated buildings.
4. **Financing for the electric mobility ecosystem:**
    - Connecting Europe Facility: The European Union fund for investments in infrastructure in transport, energy, and digital services projects, aimed at greater connectivity among the bloc's Member States. This funding includes the development of charging infrastructure at the European level.
    - Horizon 2020 and European Investment Bank: Also support projects focused on research and innovation in electric mobility. One example is the Cobalt-free Batteries for Future Automotive Applications (COBRA) project, funded by the Horizon 2020 research and innovation program, which received a grant of EUR 11.8 million to develop next-generation cobalt-free batteries.
    - Innovation Fund: Plans to invest EUR 10 billion by 2030 in projects aimed at promoting low-carbon technologies and energy efficiency.
5. **Charging technical standards:** The publication of Directive EU/2014/94, which defines the technical standards for charging stations, public and residential, such as the difference between slow and fast charging and the regulation of agents responsible for providing this service.
6. **Development of the battery production chain:** The European Battery Alliance brings together governments, industrialists, and banks interested in developing a battery ecosystem in Europe. Along the same lines, the Strategic Action Plan for Batteries, the European Commission's action plan, defines concrete goals to support the battery industry, aiming at guaranteeing access to raw materials and developing a qualified workforce.

3.1.3. United States

In the United States, the Low or No-emission Bus Program (LNEBP) stands out, which aims to encourage low or no CO_2 emissions by means of electric buses. This program provides funding to state and local government authorities for the purchase or lease of low- and zero-emission public transport buses, as well as the purchase, construction, and lease of the necessary support facilities, such as charging stations along urban lines. Another ambitious federal government program is Bus & Bus Facilities Investment. Just like LNEBP, it allocates resources for the subsidized purchase of low-emission or zero-emission buses, as well as for the construction of the support infrastructure for these vehicles. These resources are destined to the state and municipal governments of the country [41].

The United States ended 2020 with 2800 electric buses ordered, which represents an increase of 24% compared to 2019. Regarding the financial context of investments in electric buses, between 2013 and 2020, the Federal Transit Administration (FTA) distributed more than USD 485 million in grants for hybrid electric, battery electric, and hydrogen fuel cell buses through the program [42]. At the beginning of 2023, the FTA announced the availability of nearly USD 1.7 billion to support state and local efforts to buy or modernize buses, improve bus facilities, and support workforce development [43].

In California, the Transit and Intercity Rail Capital Program (TIRCP) was created to finance the modernization of transportation, including buses, trains, and ferries. Among the specific objectives of the program is the reduction of greenhouse gases and, therefore, supporting the adoption of electric buses. This program is responsible at the state level for encouraging the industry's growth, with California leading the country with 1100 zero-emission buses and with targets for all buses to be zero-emission by 2040 [42].

According to data from the Alternative Fuels Data Center, the data center of the U.S. Department of Energy (DOE), there are currently 329 incentive instruments (subsidies, financing programs, tax incentives) at the federal and state levels related to the promotion of electric vehicles [41].

The work presented in [41] classified the American incentives for the electrification of public transport into threeaxes of action, as follows:

1. Incentives for research into advanced batteries;
2. Filling gaps in the production chain of batteries and components (minerals' processing, recycling);
3. Tax incentives for building battery factories and electric buses.

Finally, the content in Table 1 summarizes the main policies analyzed by [41] within the U.S.

3.1.4. Latin America

In this geographical context, some countries stand out for being pioneers in the adoption of electric buses, mainly for collective public transport. The city of Bogotá, in Colombia, has demographic characteristics similar to large cities in Brazil, where the population density is higher in the outskirts and public transport is an essential service. In 2019, the city incorporated innovations into public transport contracts, separating the investment cost (CAPEX) from the operating cost (OPEX). Disassociating the purchase of vehicles from their operation made it easier to obtain financing for electric buses from financial institutions, since the greatest risk is in making the transport operation feasible [44].

In order for public transport to be accepted by society, a number of factors are necessary, such as: available schedules, quality of transport, price, and geographic coverage. With this model, periodic evaluations are made of the company responsible for the operation with the risk of non-renewal of the contract. Thus, there is one more guarantee for the quality of service and the usability of public transport, which makes investments viable.

Table 1. Summary of incentive policies for the e-bus production chain in the USA [41].

Policy	E-Bus Production Chain	Tools	Nature	Start/End
Clean Transportation Program	Financial incentives focused on innovations and construction of support infrastructure	Not specified	Consumption Stimulus	2008/2024
American Recovery and Reinvestment Act	Subsidies for the construction of battery and electric vehicle factories	Direct subsidies and tax incentives	Stimulus to National Production	2009/2011
Bus & Bus Facilities Investment program	Subsidy policy for the purchase of e-buses and supporting infrastructure	Direct subsidies	Consumption Stimulus	2016/-
Low- or No-Emission Bus program	Subsidy policy for the purchase of e-buses and supporting infrastructure	Direct subsidies	Consumption Stimulus	2016/-
Battery500	Investment program in R&D in advanced batteries	Roadmap, direct subsidies, use of government laboratories and infrastructure	Research, Development, and Innovation (RD&I)	2016/-
California Clean Truck, Bus, and Off-Road Vehicle and Equipment Technology Program	Financing for advanced R&D projects	Subsidized financing line	Research, Development, and Innovation (RD&I)	2016/-
National Defense Authorization Act	Regulation that restricts access to subsidies of demand by Chinese companies	Regulation of subsidy programs	Research, Development, and Innovation (RD&I)	2019/-
Federal Consortium for Advanced Batteries	Performing a diagnosis of the gaps in the battery production chain	Roadmap	Stimulus to National Production	2020/-
Buy America Act/Fixing America's Surface Transportation Act	Regulation establishing minimum nationalization rates for subsidized vehicles	Regulation of subsidy programs	Planning & Governance	2020/-
Infrastructure Investment and Jobs Act	Subsidy policy for the purchase of e-buses, investment in infrastructure and R&D in advanced batteries	Roadmap, direct subsidies, and tax incentives	Planning & Governance	2021/-
Clean School Bus Program	Subsidy policy for the purchase of school e-buses	Direct subsidies	Research, Development, and Innovation (RD&I)	2022/2026
Battery Recycling Research, Development, and Demonstration Grant Program	Battery recycling R&D investment program	Direct subsidies	Stimulus to National Production	2022/-

In Santiago, Chile, an innovative model that involves bodywork manufacturers, automakers, and a financial institution in a partnership has been a reference for the electrification of public transport. In this model, the company establishes a leasing contract for the provision of the fleet with cities or transport operators. Thus, the financial institution buys the fleet from the manufacturer and rents it to cities and operators, with the government being responsible for guaranteeing the payment of the leasing quota even when there is a change of operator. Another interesting characteristic of this model is that, in the case of electric buses, the role of the financial institution is taken over by energy companies, and not by banks. Thus, the local energy company pays for the electric buses and guarantees the energy supply for the system [44].

3.2. Brazilian Scenario

A positive factor is that several Brazilian companies are already electrifying their fleets and have the intention to go even further. As an example, a giant food company, in 2021, already had an electric truck in operation in Brazil. Furthermore, in 2022, it acquired thirty new vehicles that started to run around the country and announced the launch of a company specializing in leasing electric trucks [45].

In addition, a car rental company already had 400 EVs in 2021 and announced the goal to neutralize its carbon emissions by 2028, so it set aside BRL 370 million to purchase 2000 electric cars in 2022 [46].

On the other hand, specialists point out that Brazil is still far from many countries that have already implemented specific strategies in order to encourage vehicle electrification. Although all the advantages that EVs provide are known, regulation is essential to direct and guarantee electric mobility in Brazil. The following section presents the regulatory initiatives created to boost electromobility in Brazil at the Federal Executive and Legislative level, based on the legislative panorama of electromobility.

3.2.1. Federal Executive

At the Federal Executive level, the following norms are in force:

- **ANEEL Normative Resolution No. 1.000/2021**

It consolidates the rights and duties of electricity consumers and establishes the Rules for the Provision of the Public Electricity Distribution Service [47]. The provisions of the installation of electric vehicle chargers are in Chapter V of the normative resolution. The Agency opted for a minimum regulation of the subject, aiming to avoid undesirable interferences in the operation of the electrical network and the guarantee that the electricity consumers' tariff is not impacted by the provision of the electric vehicle charging service.

- **Rota 2030**

This is a Federal program regarding the automotive chain, aiming to support technological development, competitiveness, innovation, vehicle safety, environmental protection, energy efficiency, and the quality of cars [48].

It is a long-term public policy program aimed at the development of the automotive sector in the country with the transformation of vehicles, in the way that they are used and produced, with three central strategies [48]:

1. The establishment of mandatory requirements for the sale of new vehicles produced in the country or the importation of new vehicles;
2. Tax benefits to the companies that spend on R&D in the country;
3. The Regime of Non-Produced Auto Parts.

- **International Trading Board (CAMEX), Resolution 97/2015**

Resolution 97/2015 reduces the Import Tax on EVs from 35% to between 0% and 7%, depending on the aspects of the vehicle [49].

- **Presidency of the Republic**

Decree No. 9.442/2018 established at between 7% and 20% the Taxes over Industrialized Products (IPI) rate levied on hybrid vehicles and EVs. It was repealed by Decree No. 11.158/2022, which caused the rate to change to values up to 22.75% [50].

Law 14.000/2020 amends Law 12.587/2012 and determines that municipalities must prepare and approve their Urban Mobility Plan within the following deadlines: by 04/12/22, for municipalities with more than 250,000 inhabitants; by 04/12/23, for municipalities with up to 250,000 inhabitants [51].

3.2.2. Federal Legislative

At the Federal Legislative level, the most-relevant Law Projects (PLs) pending are presented below:

- **PLS 340/2016**: Exemption of taxes over industrialized products, for up to 5 years, on domestically manufactured EVs and hybrids;
- **PL 7482/2017**: Differentiated taxes over industrialized products' rate for EVs;
- **PL 5590/2019**: Allows energy distributors to install charging stations, paid by a group of consumers who express interest, through prepaid tariffs;
- **PL 6246/2019**: Prohibition of combustion vehicles' manufacturing and marketing (January 2030) and circulation (January 2050);
- **PL 3339/2019**: Maximum of 25% fossil fuel vehicles by January 2035. Exemption from taxes on industrialized products and import taxes. Differentiated rate for corporate income tax, social contribution to net income, contribution to social security financing, financial transaction tax, contribution to intervention in the economic domain, property tax on motor vehicles, personal injury caused by land vehicles and annual licensing;
- **PL 5308/2020**: Provides tax incentives for operations with electric or hybrid motor vehicles;
- **PL 808/2021**: Determines the installation of infrastructure for recharging EVs in buildings for collective use;
- **PL 2461/2021**: Creates MoVE Brasil, which deals with measures to encourage the transition to non-polluting transport and the installation of charging stations for EVs;
- **PL 2156/2021**: Provides the guidelines for the National Electric Mobility Policy and makes other provisions;
- **PLS 403/2022**: Grants exemption from the Import Tax on electric and hybrid vehicles;
- **PLS 304/2017**: Amends the Brazilian Traffic Code to prohibit the sale and movement of cars powered by fossil fuels based on the established terms;
- **PLS 454/2017**: Amends the Pollutant Emission Reduction Law to prohibit the sale of combustion-powered vehicles in the country after 2060;
- **PL 2327/2021**: Determines that the reverse logistics of electric vehicle batteries should prioritize the recycling and reuse of its components in the manufacture of new batteries;
- **PRS 64/2021**: Establishes the Joint Parliamentary Front for Electromobility—FPELETROMOBILIDADE;
- **PL 2662/2022**: Establishes an incentive for new buildings, shopping malls, and other constructions to have electrical installation in their garages for charging EVs;
- **PL 6020/2019**: Amends Law No. 9478, from 1997, Law No. 9991, from 2000, and Law No. 13755, from 2018, to encourage research on electric mobility in Brazil.

The status of each of the aforementioned legislative activities is shown in Table 2.

Between 2019 and 2021, seven relevant bills were filed, in addition to the opening of ANEEL Grant 011/2021. It aims at obtaining subsidies for the preparation of proposals for regulatory models. These models are for the insertion of distributed energy resources, including EVs. Therefore, this ensures that electromobility has gained space. In order to further intensify the theme, regulatory propositions are presented next.

Table 2. Legislative activities mapped.

Legislative Activity	Last Action Date	Last Action	Current Situation
PLS 340/2016 [52]	22 December 2022	Archived at the end of the Legislature	Archived at the end of the Legislature
PLS 304/2017 [53]	21 December 2022	Archived at the end of the Legislature	Archived at the end of the Legislature
PLS 454/2017 [54]	21 December 2022	Archived at the end of the Legislature	Archived at the end of the Legislature
PL 7482/2017 [55]	19 March 2019	Unarchived	Attached to PL 1609/2007
PL 5590/2019 [56]	21 December 2022	Continue to process	Matter with the rapporteur
PL 6020/2019 [57]	19 May 2022	Awaiting designation of the rapporteur	In process
PL 6246/2019 [58]	01 June 2021	Attached to PL 1712/2021	Attached to PL 3339/2019
PL 3339/2019 [59]	3 December 2019	Attached to PL 6246/2019	Attached to PL 1609/2007
PL 5308/2020 [60]	10 March 2021	Received by CDEICS	Attached to PL 4086/2012
PRS 64/2021 [61]	24 March 2022	Enacted on 02/23/2022	Approved by the plenary
PL 808/2021 [62]	21 December 2022	Continue to process	Awaiting dispatch
PL 2461/2021 [63]	21 December 2022	Continue to process	Awaiting dispatch
PL 2156/2021 [64]	24 August 2022	The period of 5 sessions for submitting amendments to the project ended. No amendments were submitted.	Awaiting the opinion of the rapporteur
PL 2327/2021 [65]	21 December 2022	Continue to process	Awaiting dispatch
PLS 403/2022 [66]	21 December 2022	Continue to process	Matter with the rapporteur
PL 2662/2022 [67]	21 October 2022	Continue to process	Awaiting dispatch

4. Regulatory Proposals

Based on research, studies, and experiences during the implementation of the pilot, this section presents the propositions that should be encouraged, created, or changed in the regulatory scope in order to support the electric mobility sector.

4.1. Taxation and Pricing on Recharges

As shown in Section 3.2, an important regulation for EVs is ANEEL Normative Resolution No. 819/2018, which allows commercial exploration at freely negotiated prices for EVs' recharging. However, for commercial exploitation to take place, a minimum of legal certainty is required in relation to the correct way of taxing top-ups.

In this context, the current discussion revolves around understanding what would be the appropriate way to tax the sale of energy for recharging EVs, considering it as a service or considering it as a product. These classes present rates with significant differences in tariffs. These differences are accentuated when considering different geographic regions. The lack of regulation brings insecurity and drives away investments in charging stations, as the operating costs and revenue predictability are not clear [68]. Thus, to encourage investments and facilitate the development of different businesses in electric mobility, it is essential to regulate pricing, as done in Germany, Spain, the United Kingdom, and California, according to Technical Note No. 0041/2022 ANEEL [69].

With the growth in the penetration of EVs, there is also an increase in network impacts. In this case, pricing plays a key role in guiding user behavior, and through dynamic pricing, it is possible for electric vehicle owners to become agents, responding to price incentives for recharging vehicles at times that do not congest the network.

ANEEL can regulate the maximum and minimum tariff prices for charging, to avoid divergences and abuses. However, it should be up to the distributor to estimate and calculate the load at the connection points and use price modulation to guide consumer behavior, within established limits. With dynamic pricing, it is possible to modulate prices for a better spatial distribution of charging, avoiding overloading specific transformers, and better temporal distribution throughout the day, through more attractive prices at off-peak times. Furthermore, for stations that have local renewable generation, price modulation can encourage simultaneity between generation and consumption, which is desirable for the network.

Thus, the measure generates benefits for the distributor, with profits from recharge prices, better control of loads, and the stability of its network. As for the users of EVs, they can charge at better prices, face shorter queues, and contribute to postponing investments in the network. Furthermore, there are incentives for the entire local society, which benefits from the use of EVs, due to their zero level of pollution and noise. Figure 5 shows a graph with the relation between the recharge price and the expected impact on availability over time.

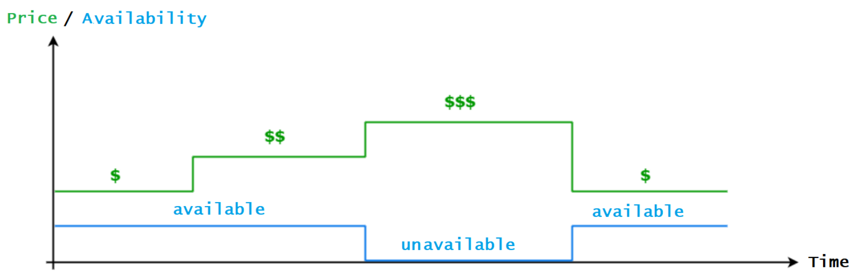


Figure 5. Relation between recharge price (low—$, medium—$$ or, high—$$$) according to availability.

Demand-related dynamic pricing is an innovative solution to the problem of the grid penetration of EVs. Currently, in the U.S., the states that carry out dynamic pricing vary the charging method between: a tax in USD/min that is modulated depending on the time of day; a fixed tax per block of hours with charging for idle time; there are still public stations that charge in USD/kW for demand at peak billing. Although at residential charging stations, the rate is generally the same as at home, it is very common for public stations to have different rates for every time of day, guiding consumer behavior and, consequently, reducing the impact on the network. As an example, Reference [70] proposed a dynamic pricing model to be applied at semi-fast charging stations with a focus on corporate EV fleets.

The norm, however, was revoked with the approval of the new Normative Resolution No. 1.000/2021, which consolidates the rules for the provision of the public electricity distribution service, including the rules for electric vehicle recharge facilities (Article 550 and after) [47]. Nevertheless, from the tax point of view, there is still no exact definition of the taxes that should be levied on stations that charge EVs [71].

However, ANEEL issued Normative Resolution No. 819/2018 (replaced by Normative Resolution No. 1000/2021 [47]), providing that the recharging activity must be considered a service, dissociated and distinct from the electricity supply activity. Thus, it would be possible to state that the charging of EVs is characterized as a service provision, since the supply of electric energy is an input of this activity and not an activity in and of itself [71].

4.2. Electrified Public Transport

The transition to clean public transport in Brazil is necessary. The transition challenges are the high costs for electric buses' acquisition. By overcoming these, it is possible to accelerate the adoption of electrified fleets and enjoy all their benefits, such as the reduction of emissions and pollution, the improvement of the population's health, and the qualification of bus services.

Although the country has a robust fleet of more than 100,000 buses, less than 1% consist of low- or zero-emission buses. The offer of electric buses at more competitive prices can be a part of the solution to increase the size of the electrified fleet circulating in Brazilian cities, along with the support of tax incentives and new public transport concession contract models.

Currently, Brazil already has two factories installed—the Brazilian Eletra and the Chinese BYD—and also, six other electric bus manufacturers have shown interest in the Brazilian market—Foton, Higer, Mercedes-Benz, Skywell, Sunwin, and Zhongtong. It turns out that even Brazilian factories are dependent on imported components, which generates a very significant tax burden on the sale of electric buses in the country. In the case of vehicles purchased abroad, the final cost doubles because of the taxes [44], such as import taxes, taxes on industrialized products, social integration programs, the contribution to social security financing, and taxes on the circulation of goods and the provision of services.

There have already been reductions in the rates of these taxes, but these could be made even more attractive. If there were relevant tax incentives, automakers would feel encouraged to produce EVs in the country, and local production would be essential to reduce the prices. In 2022, that number continued to grow. In November, 727 units were sold. This represents an increase of 13.59% compared to the previous month, and this number translates into a significant increase of 67.13% year-on-year [72]. This jump in sales occurred even with high prices and without any measures by the Federal Government [73,74].

Thus, as in Chile and Colombia, Brazil can follow in the same direction, guaranteeing tax incentives that reduce the main taxes on a temporary basis [44]. These measures should minimize the high capital costs, making it feasible to import the complete bus and its components, contributing to the sector's competitiveness.

In addition to imports, the country should also take advantage of its already established industrial capacity. It should encourage the development of the local industry of EVs of all categories (light and heavy). This long-term action has the potential to generate jobs and to position Brazil as an exporter of technology, as already is the case for diesel vehicles.

The importance of an integrated national plan between municipalities, states, and the federal sphere is also highlighted, which connect and coordinate actions for the transition to electromobility. In addition to clear guidelines, solutions for financial stimulus, and the promotion of local industry, policies must consider other challenges that arise with the acquisition of vehicles, such as the disposal of batteries and adaptations to the electricity network.

In addition to tax incentives, new models of concession contracts are essential for the transition to electrified public transport. Currently, the concession contracts are between 15 and 20 years long, with disputes only in the bidding process, and over that period, the loss of the quality of service and the deterioration of vehicles are accentuated. Following the example of the innovations implemented in Colombia, two viable alternatives are the reduction of concession terms and the separation of the fleet provision and operation contracts.

An innovative model from Santiago, Chile, that can serve as an inspiration is the operating contracts with short terms of 5 to 7 years, which can be extended according to the indicators of service quality and customer satisfaction [75]. As for the provision of the electrified fleet, an alternative is the leasing contract, in which the financial entity buys the fleet from the manufacturer and rents it to cities and operators. The government guarantees that payment of the leasing quota is prioritized and maintained even when there is a change of operator. With this model, 776 electric buses have already been provided to the city, enabling new financing. The financial entity was traditionally banks, but in this new model, it is the city's energy companies that, in addition to paying for EVs, also supply the electricity for the operation of the system. This arrangement allowed Santiago to overcome the high initial investment needed to acquire the EVs and build the charging infrastructure, making it the leader in fleet electrification in Latin America [75].

Despite the challenges, electromobility in public transport is a necessary solution for cities and the country. Investing in the energy transition means maintaining Brazil's historical role in the heavy vehicle industry and providing a public transport system with lower levels of emissions and of higher quality, making it more attractive to people. In this context, it is recommended to intensify participation in public hearings and consultations for tax incentives and for integrated plans aimed at electromobility, mainly in the context of heavy EVs, which could obtain lower taxes, due to the numerous benefits they add to society. At the municipal level, the formation of special commissions for studies and public transport projects is recommended. Projects that aim to obtain subsidies in order to ensure that concession contracts incorporate new technologies can improve the quality of service and support the electrification of the fleet.

4.3. Incentives for the Battery Industry

Batteries represent up to 40% of electric vehicles' total price, which is the main factor that maintains their high price when compared to combustion vehicles [74]. Due to recent events, such as the COVID-19 pandemic, the increase in the demand for batteries' raw materials, political instability in countries that compose the battery supply chain, and the semiconductors crisis, the cost of batteries has increased significantly [76,77]. In the Brazilian case, this increase impacts the market even more since the import taxes tend to be high and are based on a percentage of the product price. Consequently, these factors make the financial viability of new sustainable businesses using EVs difficult.

In order to achieve a battery cost reduction and national industry development simultaneously, it is necessary to seek alternatives that not only reduce the taxes on import products, but also create the conditions to develop those products and the related industries, nationally.

An alternative is to use the Lei do Bem (Law No. 11,196/2005), where private industry is encouraged, through tax reductions, to invest in technological innovation [78]. In this law, through R&D and since the required tax framework is met, tax reduction incentives cover both the design of new products and manufacturing processes, as well as the addition of new functionalities or characteristics of the product or process, generating improvements and increasing quality, which result in greater competitiveness in the market. Considering the improvement of the national battery industry, this alternative falls under the experimental development category, which comprises systematic works based on pre-existing knowledge, with the aim of proving or demonstrating the technical or functional viability of new products, processes, systems, and services or improving the existing ones.

Another suitable measure is to promote along with the National Development Bank (BNDES) the expansion of the specific financing for electric vehicle batteries for public transport, thus encouraging the private and governmental sectors to invest and improve urban mobility and, consequently, reducing greenhouse gas emissions and noise pollution in the major cities. Currently, only three battery models are considered in the list of financeable equipment by BNDES Finame, which is the financeable list for equipment with low carbon emissions [79]. By increasing this list, the purchasing possibilities may also be expanded, and consequently, competition in the market would reduce the prices.

Figure 6 presents the BNDES investments over the last 26 years, where the exponential decrease in the funding of low-carbon products can be observed. From 2010 to 2015 alone, photovoltaic energy was widely disseminated and financed by BNDES, so batteries for large EVs can find space in this line.

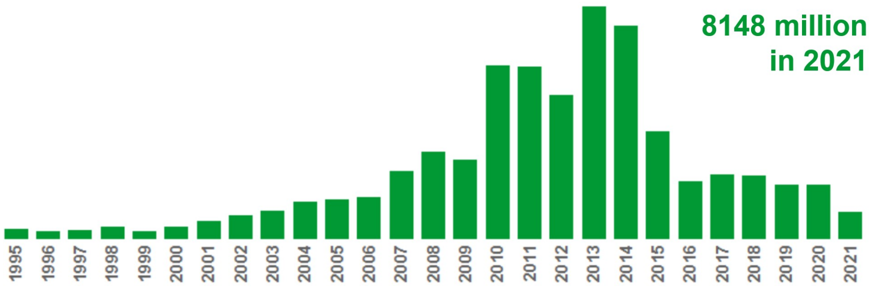


Figure 6. Investments made by BNDES in low-carbon products.

4.4. IEC 61851-1 Compliance

During the development of the Electrical Bus R&D project, charging tests were performed with the BYD bus using the WEG station. In the initial tests, several problems arose, making it impossible to proceed with a proper and secure charging process. Those problems were related mostly to noncompliance with the standard IEC 61851-1 (Electric vehicle conductive charging system—Part 1: General requirements) [80], which standardizes the communication between the charging station and the electric vehicle.

4.4.1. Diode Failure

The first attempt to charge the BYD bus with the WEG station presented an error that did not allow the continuity of the charging process. Analyzing the station log, an error named "ERR_DIODE_FAILURE EVCommunicationError" showed up. This error was due to a missing diode in the BYD bus side's control pilot circuit. This circuit is standardized by IEC 61851-1, and its circuit is detailed in A.2 section (Control pilot circuit). Figure 7 shows the missing diode scenario.

The WEG maintenance team added the diode to the charging station's side, and the charging process evolved to the next phase of communication, as this was no longer a problem.

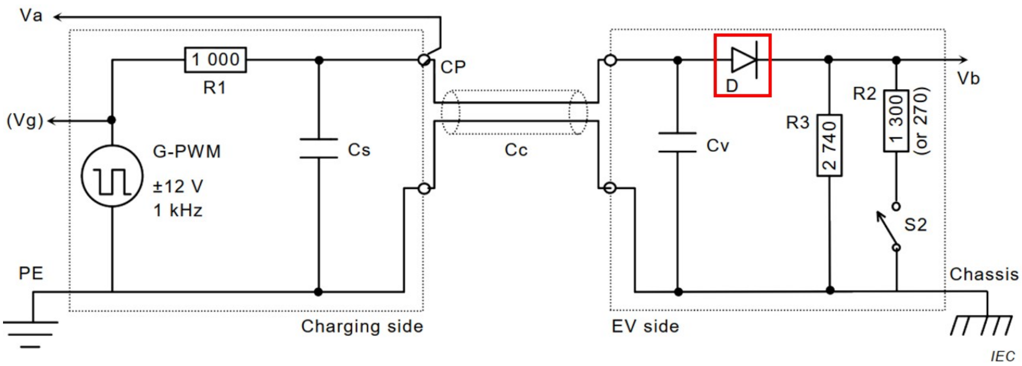


Figure 7. Typical control pilot circuit (equivalent circuit) highlighting the missing diode in the BYD bus.

4.4.2. Poor PWM Signal Quality

After the diode problem was resolved, another problem was detected by the WEG team. Analyzing the voltage level of the communication between the station and the vehicle, it was found that there was unusually high noise on the control pilot (CP) signal communication line, used for the communication between the charging station and the EVs, making it impossible to correctly read from the controller, which disabled the charging process. Figure 8 shows the communication signal between the WEG station and the BYD bus obtained by an oscilloscope.

The signal format is defined in IEC 61851-1, and it is presented in Figure 7 as having the source (G-PWM) at the charging station's side. The communication is based on a PWM signal with a 12 VDC peak and a frequency of 1 kHz, where the duty cycle of this signal indicates the maximum current that the charging station can provide.

Figure 8. Communication signal between the WEG station and the BYD bus.

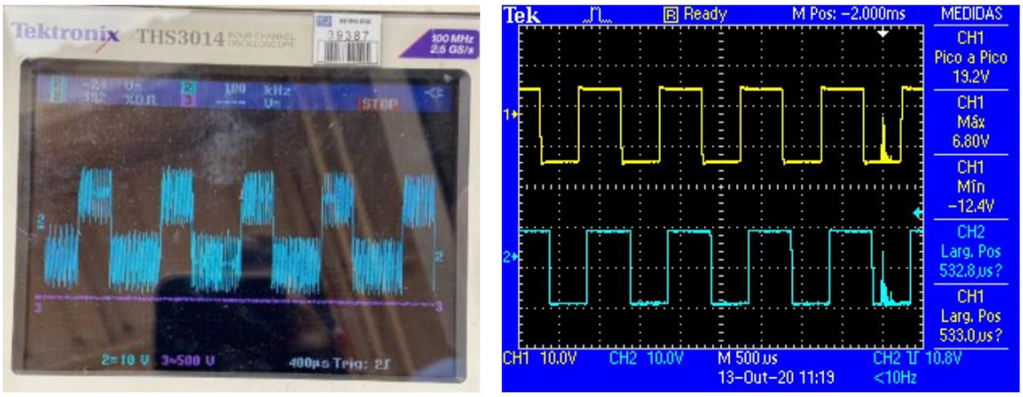
After the WEG team implemented a filter based on capacitors and inductors on the charging station's side, the communication signal between the charging station and the vehicle normalized to the expected standards, as can be seen in Figure 9. However, in some cases, another signal pattern different from the standard appeared during the charging process, which led to the charging station ending the communication, as can be seen at the end of the PWM signal in Figure 9. To address this problem, BYD executed a firmware update on the electric bus that corrected the problem.

Figure 9. Communication signal between the WEG station and the BYD bus after implementing a filter with capacitors and inductors.

For comparison purposes, the same tests were conducted in three different scenarios. The signal communication during a charging process was monitored by an oscilloscope for:

- BYD charging station with the BYD bus;
- WEG charging station with the Volvo XC60;
- WEG charging station with the Chevrolet EV Bolt.

The results are presented in Figure 10, where it is possible to observe that the communication between the BYD devices (charging station and vehicle) did not follow the standard IEC 61851-1, presenting high noise. Meanwhile, the communication between the WEG charging stations and other EVs on the market followed the standard requirements.



(a) (b)

Figure 10. Communication signal comparison. (**a**) BYD charging station with BYD bus. (**b**) WEG charging station with Volvo hybrid XC60 (yellow signal) and Chevrolet EV Bolt (blue signal).

4.4.3. Residual Current Device

Besides the communication issues, another problem was the residual current device (RCD). The BYD D9F bus is built according to IEC 61851-1 from 2013, according to BYD. This means that the required residual current device in this standard (2013 version) is Type A. However, during the project, the standard considered by the Brazilian organizations based on IEC 61851-1, NBR ABNT IEC 61851-1 [81], was updated from IEC Version 2013 to Version 2017. In this new version, the required RCD must be Type B, for which the WEG station is already in compliance.

In order to achieve the maximum power during the charging, the D9F bus is connected through both connectors available at the WEG station. However, in this scenario, the WEG station RCD is always triggered, and the charging is finished. This occurs because, when the bus is charged through both connectors, the onboard charger presents a power imbalance. If only one connector is used, the RCD is not triggered. RCD Type B was replaced by RCD Type A, and the charging process occurred normally. However, this configuration, with RCB Type A, is no longer allowed due to the update of ABNT NBR IEC 61851-1.

4.4.4. Analysis and Propositions

During the development of the R&D project, one of the main standards that defines the minimum technical requirements for electric vehicle charging systems in Brazil, ABNT NBR IEC 61851-1, underwent an update. In the middle of the project, this standard, based on IEC 61851-1 of 2013, was updated to the standard of the 2017 version, which in this case impacted specifically the type of RCD required, from Type A to Type B.

As mentioned, this standard update impacted the charging process level, making it impossible to perform any charging in the D9F bus using the WEG station. While the WEG station was already compliant with the new standard applying the Type B RCD, the BYD D9F bus was compliant with the older version of the standard for RCD Type A, since it was built and bought before the standard's update.

This case highlights the need for the correct alignment between the industry and the regulatory organizations. Definitely, constant improvement of the standards is important to provide safety and quality to the users. However, it is also important that the manufacturers and the regulatory organizations have a mutual understanding of how new standards' updates can be applied without harming the final consumer.

On the other hand, this case also highlights the need for a constant inspection of the manufacturers in order to guarantee the compliance with the standards. Despite the update of the standards, some requirements did not change, such as the signal communication pattern and the CP circuit.

In these times when the electromobility sector in Brazil is still at the beginning compared to other countries, the players still need to perform much work to raise awareness, demonstrate the benefits, and learn how the market works to obtain new consumers. Cases such as the "diode failure" and the "poor PWM signal quality" evidence that some manufacturers do not follow the standards, and this can harm the sector's visibility, causing it to appear as an immature technology, which does not work and which can leave the consumer helpless, consequently discouraging the consumer from being a part of the electromobility sector.

4.5. Plugs and Connectors' Standardization

Currently, there is a wide range of different types of connectors for charging EVs, both for AC and DC charging. These connectors are defined by different standards, such that in the United States and in part of the Pacific countries, the standardization is managed by the Society of Automotive Engineers (SAE), whereas in most countries in the world, and mainly in Europe, the IEC manages the normalization. In China, Guobiao Standards (GB) is in charge of its standardization [82,83]. Figure 11 shows the different types of connectors for AC and DC charging, as well as the regions where they are mostly used, according to the local standards.

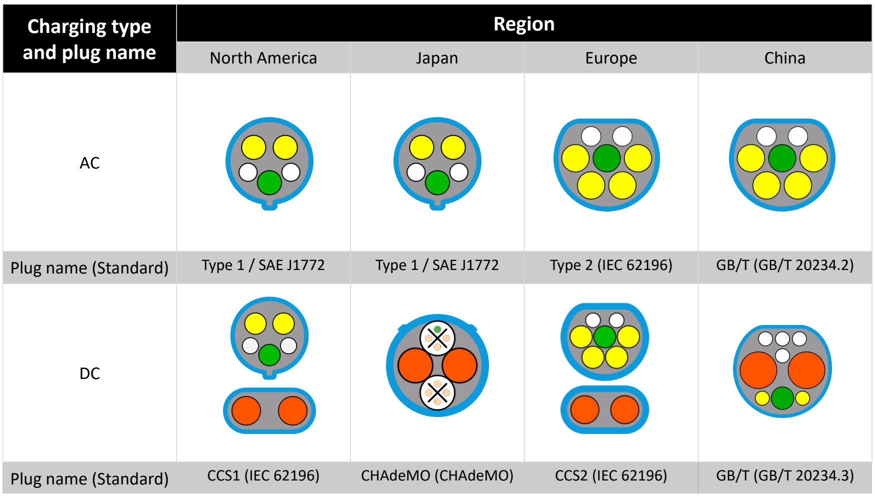


Figure 11. Types of connectors for electric vehicle charging.

In the Brazilian context, there is still no norm that standardizes which plugs and connectors should be adopted between the electric vehicle and the charging station. However, some tendencies have been observed, given the increasing penetration of EVs in the country. Until the emergence of new models, which has increased since 2020, the Nissan Leaf was the leading model with a CHAdeMO connector, indicating that this would be the way forward. Meanwhile, Nissan decided to opt for the CCS standard in the U.S. and Europe, with Japan being the only exception to continue with CHAdeMO. In this case, it should be noted that some models still use the CHAdeMO connector, for instance the Lexus UX300e and the XPENG G. However, the best-selling EVs in Brazil, such as the Volvo XC40, Volvo C40, Caoa Chery iCar, Renault Kwid E-Tech, BMW i3, Audi e-tron, Renault Zoe, Chevrolet Bolt, Jaguar IPACE, and Porsche Taycan, among others, use the CCS-Type 2 connector, according to the Brazilian Electric Vehicle Association (ABVE) [23]. In addition, most fast charging stations provide three connectors: an AC connector, Type 2, standardized by IEC 62196-2 [84], and two DC connectors, CCS-Type 2 and CHAdeMO, standardized by IEC 62196-2 and the CHAdeMO Association, respectively.

In this context, it is noteworthy that the establishment of the technical standardization of charging stations is extremely important for the expansion of electric vehicle charging networks and sector planning [27]. The standardization must occur on a technical and statistical basis, in order to define, through the creation of a Brazilian norm, which connectors must be used for AC and DC charging, based on current international standards.

In the same direction, although adapters for DC connectors exist, it is suggested that such devices should not be recommended by local standardization authorities, due to the high power involved during charging, with the increased risk of overheating points in the case of an inappropriate connection. Furthermore, it is expected that the CHAdeMO connector will still be allowed, given the large circulation and sales contribution of the Nissan Leaf model, characterized, until now, as being one of the only vehicles capable of implementing the vehicle-to-grid (V2G) strategy. Otherwise, the Type 2 AC connector is easily adaptable to other AC standards of auto manufacturers, such as GBT/AC or Type 1.

In the future, Chaoji (mixed standard between CHAdeMO and GBT) will use CAN communication and will possibly allow the use of adapters. Thus, it is expected that the standardization of public charging stations for EVs in Brazil will follow the European standard, including the possibility of a third connector in fast stations compatible with CHAdeMO or GBT, allowing the charging of these vehicles that are already in the national territory. On the other hand, for public semi-fast stations, the current standardization trend should be normalized to Type 2 with alternating current.

4.6. V2G Regulation

V2G technology aims to enable the provision of services to the grid in discharge mode. Thereby, the electric vehicle can be charged at a certain time of the day and, at an appropriate later time, be discharged in order to supply power to the grid at a convenient location [27]. In this sense, power system operators are able to purchase energy from their customers, either for supply during peak demand or to provide ancillary services to the grid, such as frequency and voltage regulation [85].

In the international scenario, studies have shown that several countries are in the early stages of applying V2G technology, in the pursuit of understanding its functioning through pilot projects. In the United States, for example, pre-commercial solutions are already found to support the network in places with non-robust electrical infrastructures [85]. In Europe, a large number of pilot projects have been developed, stimulated mainly by local energy management, as seen in Denmark, Germany, the Netherlands, and Spain [85]. In the same sense, although commercial actions have not yet been implemented, it stands out that, since 2019, auto manufacturers such as Nissan, Mitsubishi, Toyota, BYD, and Renault have been actively involved in vehicle-to-everything (V2X) initiatives [85]. In this context, heading towards the fulfillment of the decarbonization goals affirmed by several countries, the possibility of injecting into the grid the energy from the batteries of EVs presents itself as a relevant factor to strengthen the electrical system in the energy transition [86].

Thus, it can be observed that V2G technology can be especially beneficial if used by heavy fleets, such as public transport, school buses, or charter vehicles. These fleets are generally characterized by substantial battery storage and long idle periods. Thereby, for public transport fleets, it would be interesting to evaluate short routes that surround high consumption points (shopping centers, malls) in peak demand periods. This way, the buses could be used as a source of energy for local consumption at these points. School and charter fleets, on the other hand, could supply power to the grid during long periods when they are idle, such as nights and weekends, or during even longer periods, such as the vacation season. Because of their high storage capacity, electric bus batteries could be used as a backup source for local infrastructure in case of a power outage of the main grid, in vehicle-to-building (V2B) or vehicle-to-home (V2H) mode, or for peak demand shaving, possibly avoiding the use of fossil-fuel-based generators such as diesel generators.

However, for the large-scale implementation of V2G, it is known that some challenges need to be overcome. In general, these are: insufficient appropriate charging infrastructure that supports the use of V2G technology [85]; the absence of V2G mode in most of the electric vehicle models [85]; the possibility of vehicle battery degradation during discharge to supply power to the grid [87]; the recent publication of ISO 15118-20, which updates the CCS protocol with the V2G functionality; therefore, recent technology needs time for its maturation in the market through new products [88,89].

In the Brazilian context, in addition to the technical aspects, the prohibition of V2G technology presents itself as the biggest barrier so far. In this scenario, it is considered that the regulation should not prohibit V2G technology. Initially, a call for ANEEL R&D projects is suggested, so that, with pilot projects, it is possible to carry out the necessary studies to overcome the current obstacles and increase the field of knowledge about this technology, following in the steps of those nations that are further along the path to electromobility.

Given this context, in the next three years, the investment in studies on the impact of V2G technology on the grid is suggested, essentially with a call for ANEEL R&D projects focused on the topic. In up to five years, the results of the pilot projects should be evaluated, and auxiliary infrastructures for the implementation of V2G technology should be made feasible. Within this horizon, the CCS protocol will already be qualified for the use of the technology, if it becomes the standard adopted in the country. Then, in six years, a regulation for V2G must be created, based on the norms that have been developed in countries where the technology is more advanced.

Likewise, it is considered fundamental to include in a more significant way the possibility of the injection of energy into the grid from EVs in the long-term National Energy Plan (NEP), for an exploration beyond the concept of clean transport and the possibility of charging EVs from the distribution grid (grid-to-vehicle), in order to achieve the development of a more secure electric system [86].

5. Conclusions

It is possible to observe that the growth of heavy electric vehicle fleets in the international scenario stems from government initiatives for zero emissions. From just the economic point of view, the acquisition of EVs at the current prices is not feasible in all cases, mainly due to the high costs involved compared to combustion vehicles. However, when there are goals to meet, mainly environmental responsibility, the governments involved invest in these fronts and provide subsidies, and there is an increase in heavy EVs.

In this context, the paper presented the main barriers and recommendations for the electromobility sector in Brazil during the development of the R&D project presented in Section 2. Section 4 was the result of the interaction with several stakeholders of the electromobility sector, allied with the problems found during the implementation of the charging infrastructure shown in Figure 2 and the use of the electric bus by a partner company from the transportation sector.

It was observed that, during the idealization and development of the proposals, due to the high cost of the technologies involved in the manufacture of batteries, heavy EVs still require incentives to be disseminated. It is hoped that, with the popularization of the technology, the costs will reach lower levels and the market will manage to self-regulate. However, while this is not yet a reality, governments that have shown commitment to this agenda are replacing diesel fleets with battery fleets. This can take be initiated in the public sector, both in the federal and municipal context, mainly with public transport. The next step would be partnerships with energy companies to expand the charging infrastructure and carry out technical studies and necessary adjustments to the distribution system. For the sector to be sustainable in the long term without the need for subsidies, it is essential to strengthen the national industry and technology. Thus, it is expected that prices will be reduced with the dominance of the technology, and consequently, the popularization of EVs will increase, enabling the creation of economically self-sustaining business models.

Finally, the growth of this sector without any regulation can result in negative publicity, for example products that do not follow established international regulations. In this way, the need for the standardization and regulation of communication interfaces between vehicles and charging stations and specifications for installing charging stations is reinforced, so that interoperability is guaranteed, in addition to other advantages such as product quality and safety for the user.

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Abbreviations

The following abbreviations are used in this manuscript:

ABVE	Brazilian Electric Vehicle Association
ANEEL	Brazilian Electricity Regulatory Agency
BEB	Battery electric bus
BEV	Battery electric vehicle
BNDES	National Development Bank
CAGR	Compound annual growth rate
CAMEX	International Trading Board
CAPEX	Investment cost
CO_2	Carbon dioxide
CP	Control pilot
EV	Electric vehicle
FCEB	Fuel cell electric bus
FTA	Federal Transit Administration
GB	Guobiao Standards
GHGs	Greenhouse gases
HFCV	Hydrogen fuel cell vehicle
IPI	Taxes over Industrialized Products
LNEBP	Low or No-emission Bus Program
NEP	National Energy Plan
NEV	New energy vehicle
OPEX	Operating cost
PL	Law projects
PWM	Pulse width modulation
RPM	Revolutions per minute
R&D	Research and development
SAE	Society of Automotive Engineers
SoC	State of charge
TCO	Total cost of ownership
TIRCP	Transit and Intercity Rail Capital Program
V2B	Vehicle-to-building
V2G	Vehicle-to-grid
V2H	Vehicle-to-home
V2X	Vehicle-to-everything

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