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ARTICLE

Panorama of electromobility in public transport in the metropolitan area of São Paulo – Brazil

Panorama da eletromobilidade no transporte público na região metropolitana de São Paulo – Brasil

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Abstract: Electrification of vehicles emerges as an efficient way to reduce greenhouse gas emissions (GHG) in urban systems. Electric buses "E-buses" is a reality in many cities around the world. However, in Brazil, they are striving to take the streets and most of them are running in the Metropolitan Area of São Paulo (MASP). This study aims to investigate the reasons why the bus electric fleet in MASP perform arround 2% of the total buses in circulation and the future of this sector as a one way to reduce GHG emissions. To do so, we conducted a literature review using scientific articles, books, specialized magazines, and reports. The results indicated that the high acquisition cost of vehicles and operational infrastructure relate to Diesel buses are the main challenges to developing electromobility. Moreover, the aversion of bus operators to electric traction models and the uncertainty of the resale of used vehicles are factors that increase even more the non-adoption. The limitation of this study is that was considered only the literature available and a survey with government and operators in the future may help to establish a better scenario over the motives that difficult the electrc buses implementation in MASP.

Palavras-chave: Transporte público; Mobilidade Elétrica; Eletromobilidade; Ônibus Elétricos; Mobilidade Urbana; BEBs

Resumo: A eletrificação dos veículos surge como uma forma eficiente de reduzir as emissões de Gases de Efeito Estufa (GEE) nos sistemas urbanos. Os Ônibus elétricos ou "E-buses" são uma realidade em muitas cidades ao redor do mundo. Porém, no Brasil, eles estão começando a sair às ruas e a maioria deles operando na Região Metropolitana de São Paulo (RMSP). Este estudo tem como objetivo investigar os motivos pelos quais a frota de ônibus elétricos na RMSP representa cerca de 2% do total de ônibus em circulação e o futuro deste setor como uma forma de reduzir as emissões de GEE. Para tanto, realizamos uma revisão bibliográfica utilizando artigos científicos, livros, revistas especializadas e relatórios. Os resultados indicaram que o alto custo de aquisição de veículos e a infraestrutura operacional relacionada aos ônibus a diesel são os principais desafios para o desenvolvimento da eletromobilidade. Além disso, a aversão dos operadores de ônibus aos modelos de tração elétrica e a incerteza da revenda de veículos usados são fatores que aumentam ainda mais a não adoção. A limitação deste estudo é que foi considerada apenas a literatura disponível e uma pesquisa futura com governo e operadoras poderá ajudar a estabelecer um cenário melhor sobre os motivos que dificultam a implementação de ônibus elétricos na RMSP.

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1. Introduction

Climate change has been impacting the way cities deal with the travel displacements generated by people and gas emissions provoked by these movements. More and more, they are searching for viable alternatives to reduce the consumption of fossil fuels such as cleaner energies, renewable sources, or electricity. However, the implementation of these alternatives has been proved a complicated mission.

Luz et al. (2019) affirm that electromobility is one of the most promising ways of reducing gas emissions and noise pollution, but these reasons are still not enough for this change. The main reasons for that are the high cost of vehicles and infrastructure, the aversion of operators to new technology, the difficulty of resale of vehicles to smaller cities, and the lack of flexibility and operational experience.

On the flip side, electric vehicles in urban transport can be impacted in different ways. Figueiredo (2021) pointed out that the use of electric buses may drastically reduce gas emissions despite the technology is still in its early stages and has the high cost of acquiring and operating these vehicles. Silva (2020) compared the operation of an electric bus with a conventional one and showed a reduction of up to 30.2% in energy consumption and 73.3% in CO2 emissions. Vasconcelos (2020) argued that making the transition from fossil fuel to electricity is feasible and advantageous from an economic and socio-environmental point of view.

Currently, São Paulo city has a bus fleet composed of 13,345 vehicles registered until april 2024 (SPTrans, 2024). Of these vehicles, 380 are electrically powered, 201 of which are from the trolleybus system, which operates by capturing energy from the parallel overhead lines, and 179 are powered by lithium-ion stationary batteries (Bazani, 2024). Since 2018, the São Paulo city had a Fleet Replacement Monitoring Program that proposes the exchange of vehicle energy sources for cleaner alternatives (SPTrans, 2020). Considering the Metropolitan Area of São Paulo, low-emission vehicles are operated in the ABD corridor (corridor that connected São Mateus and Jabaquara in São Paulo city to the cities of Mauá, Santo André, São Bernardo do Campo, and Diadema). It was designed for the trolleybus operation in 1975 it was extended and opened in 1988.

Other projects are on the radar, electrified corridors projects such as the Bus Rapid Transit (BRTs) in São Paulo, ABC (the region in the Metropolitan Area of São Paulo connected to the capital), and Radial Leste (an important route that connects east zone to center of São Paulo) to meet sustainable commitments (Bazani, 2021). Thus, the chances of new transport technologies being tested and applied on a large-scale increase, and insofar as the technology matures, prices tend to reduce (Luz et al., 2019).

Despite these initiatives, the electromobility adoption in Brazil, and more specifically in the Metropolitan Area of São Paulo remains insignificant due to the potential and beneficial impacts of its adoption. Therefore, this paper aims to investigate the reasons why the bus electric fleet in MASP perform less than 2% of the total buses in circulation and the future of this sector as a one way to reduce GHG emissions.

2. Literature review

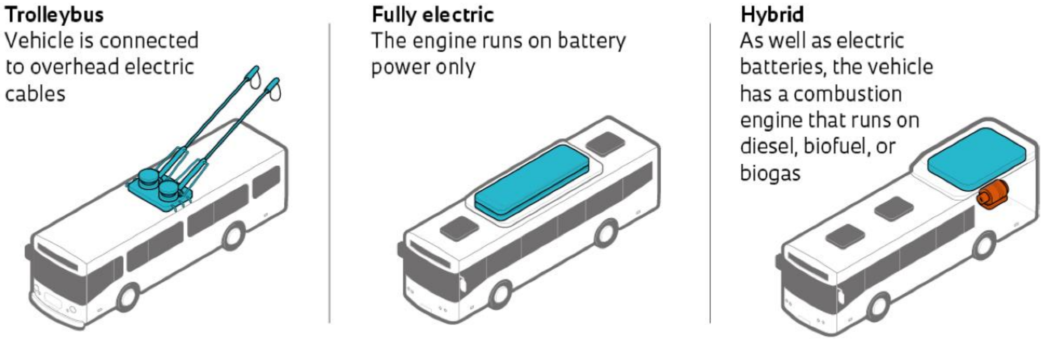
2.1 General overview

This literature review section presents the electric bus systems adopted in the Metropolitan Area of São Paulo. Nowadays, there are three available models of vehicles that operate in the context of electromobility:

- Trolleybuses are electric vehicles that operate connected to electricity.
- Battery-Electric Buses; and
- Hybrids, electric vehicles that combine an electric motor with other combustion engines, such as diesel and etanol

Figure 1 presents these three types of electric buses and Table 1 presents the number of electric vehicles in operation in the MASP.

Figure 1– Electric Buses Models



Source: Zaparolli (2019)

Table 1 – Number of Electric Buses in Operation in MASP

City	Trolleybus	Battery Electric	Hybrid	Total
São Paulo	201	179	-	380
Intercity (EMTU)	95	1	-	96
Diadema	-	7	-	7
Mauá	-	4	-	4
Santo André	-	1	1	2
São Bernardo do Campo	-	1	-	1
Vargem Grande Paulista	-	3	-	3
Total	296	196	1	493

Source: Adapted from E-Bus Radar (2023); Notícias do Transporte (2024); (Bazani & Oliveira, 2024) ; (Bazani, 2024)

São Paulo city responds by 77% of the fleet while the Metropolitan Area of São Paulo composed of 39 cities responds by 23%. Note that they operate in fact in four cities Maua, Santo André, São Bernardo do Campo, and Diadema connected to two terminals in São Paulo city.

2.2 Trolleybus

The trolleybuses are electric vehicles that travel using energy obtained from a catenary, also called a parallel overhead line. They evolved from an electric vehicle called Elekromote - created by Siemens and Holske in 1882 in Germany - but only a few years later an electric vehicle with good operating conditions was obtained. The first trolleybus lines were raised in Leeds and Bradford - England in 1911 (Ferreira, 1995).

São Paulo City implemented a trolleybuses system in 1949 with vehicles imported from the United States and England. The first line connected Praça Joao Mendes (city downtown) to Praça General Polidoro (neighborhood of Aclimaçao). Some years later, the line was expanded to the neighborhood of Pacaembu and is still be operating under the number and name "408A/10 – Machado de Assis – Cardoso de Almeida".

During the following decades, the São Paulo City's trolleybuses system expanded. In 1958, the production of national trolleybuses began, and in 1963 a study carried out by the *Companhia Municipal de Transportes Coletivos* (CMTC) found out that trolleybuses operation was more advantageous than diesel buses and trams. Despite this fact, the public authorities reduced the number of trolleybuses and increased the fleet of diesel vehicles. The CMTC trolleybuses factory was responsible for the non-extinction of this vehicle model in Brazil because even with national manufacture, vehicles were expensive due to low demand (Ferreira, 1995; Stiel, 1978, 1984).

In 1975, the SISTRAN plan (Study of a Trolleybus Transport System for the City of São Paulo) was prepared, which privileged electric buses creating a model of medium transport capacity. The plan established the project of 280 kilometers with 33 lines and 1,280 trolleybuses. However, only 9 lines and 368 vehicles were implemented (Branco, 2012; Ferreira, 1995).

In the 1980s, the Companhia do Metropolitano de São Paulo (METRO) coordinated the intercity trolleybus network project that proposed to interconnect the Metropolitan Area using segregated metropolitan corridors interconnected with other transport systems such as Subway, Metropolitan Trains, and municipal trolleybuses. Around eight corridors were planned, but only the corridor São Mateus – Jabaquara was built (Berkes et al., 2013; Ferreira, 1995).

In 1993, the city hall decided to stop the operation of CMTC and private companies assumed the municipal lines. The trolleybuses systems also were transferred to the new operators. The contract required that these operators renovate and expand the fleet. Thus, in 1998, the trolleybuses system in the São Paulo city reached its peak with 264.5 kilometers of area network, 31 lines in operation, and 552 vehicles (Albuquerque, 2019; Silva, 1999).

The twist and turns of the São Paulo trolleybus system continue and in 2004, part of the trolleybus network was deactivated, vehicles were auctioned, and they were substituted with diesel vehicles. Between 2007 and 2014, the trolleybuses fleet was completely renovated. Currently, the trolleybus network is composed of 168 kilometers and 201 vehicles.

2.3 Battery electric buses (BEBs)

Battery electric vehicles, mainly automobiles, were manufactured until the second decade of the 20th century. On a small scale, buses were manufactured for the transport of passengers. As an example, between 1910 and 1920, Rio de Janeiro operated battery-electric buses, manufactured in the United States. But, the low autonomy and weight of the old batteries, made it to develop alternative technologies such as hybrids more reliable and offer a higher autonomy due to internal combustion engines (NTU, 2019).

In November 2003, the company Arotech presented a system of zinc-air and ultracapacitor batteries that provided a 12-meter bus weighing 20 tons with all the complementary equipment, including air conditioning, to run 232 km. China has invested heavily to become a leader in this technology by producing 100% electric vehicles to serve local and global markets (NTU, 2019).

At the end of 2013 started the beginning tests with the E-bus, battery-electric buses, in the Metropolitan of São Paulo. The city hall of the São Paulo tested, with passenger weight simulation, the vehicle produced by Chinese manufacturer BYD, with a range of 250 km, to verify the performance of the vehicle during operation (Prefeitura da Cidade de São Paulo, 2013).

Furthermore, the Empresa Metropolitana de Transportes Urbanos de São Paulo (EMTU) tested an 18-meter articulated vehicle in the ABD corridor between Diadema and Brooklin, an 11-kilometer stretch, to carry out operations with an autonomy of 220 km. The bus carried out refills quick 4 minutes and long recharges in the garage (Governo do Estado de São Paulo, 2014).

In December 2018, electric vehicles began to operate commercially by Transwolff Transportes e Turismo, line "6030/10 - UNISA - CAMPUS 1 - Term. Sto. Amaro", in the South Zone of the city. This line is 29.7 km long and has 21 buses in the fleet. It transports on average 17,500 passengers per working day with 17 electric vehicles in operation.

2.4 Hybrid electric buses

Hybrid vehicles have both kinds of engines, combining a combustion engine with electric ones for propulsion in different architectures and levels. Generally speaking, the greater the level of hybridization, the greater the electrical components and the smaller the combustion engine. Hybrid vehicles are 30% to 40% more efficient than combustion models due to the use of electric motors (Vaz et al., 2015).

Hybrid technology, despite being a current trend, is centenary. In the beginning, combustion engines were unreliable and produced noise pollution and unpleasant odors. Back then the most used technologies were steam and electric traction. The steam did not sustain itself due to the low autonomy and the refueling work. However, electricity had limited battery life, so hybrid traction was used until the 1920s when the combustion engine became reliable (NTU, 2019).

The first hybrid bus was produced in Brazil in 1999 and operational tests started in 2002. It had a diesel engine that generated energy for an electric motor. Currently, there are versions with Flex engines (gasoline and/or ethanol) and versions that can operate as hybrid vehicles and trolleybuses.

Hybrid buses are between the era of internal combustion and the all-electric one. There are two types of hybrid technology applied to hybrid buses in national technology, the bus is driven only by the electric motor, through batteries, charged by a diesel generator engine, or through both ways together. In the newer models, there is also a KERS system (Kinetic Energy Recovery System) that recharges the batteries when braking. According to the manufacturer, this system reduces emissions by 95% compared to diesel (NTU, 2019; Vasconcelos, 2015).

There is also a Swedish model in operation in Brazil using an electric motor that makes the vehicle start and runs at up to 20 kilometers per hour until the diesel model enters. This diesel engine is also off during stops and traffic lights. Operating 20% in electric mode and 80% in diesel mode generating 35% fuel savings over a conventional diesel vehicle (Vasconcelos, 2015).

In Europe, existing plug-in hybrid models recharge hybrid vehicles at stopovers with a pantograph-like connector. With this system, it is possible to reduce fuel consumption by 70%, but due to the structure, it is suitable for transport corridors (Vasconcelos, 2015).

Saura Neto (2018) explained that the hybrids reduce pollutant and noise emission levels by up to 50% compared to the similar Euro V diesel, however, the investment in vehicle acquisition and maintenance is higher than similar diesel.

3. Methodology

The methodology of this study consists of a literature review regarding the use of electromobility in public transport operated by bus.

The first step of the research was to identify the electro buses running in the MASP area in the context of the implementation and evolvement of these systems in the study area. They are presented in the literature review section.

After, the second step explored some world initiatives to help us to understand the MASP context properly. Following, the third step investigated São Paulo's actions with a specific government agency, São Paulo Transporte S/A (SPTrans).

4. Results and Discussion

4.1 World initiatives

Reducing the emission of greenhouse gases is considered essential for the maintenance of life on the planet. The concern about pollution in large urban centers has led sustainable transport systems to be considered by the United Nations (UN) as one of the items of the Sustainable Development Goals of the 2030 Agenda (UN, 2015).

To illustrate the impact of a non-sustainable transport system, in 2018, 66,633 people died in Brazil due to pollution. These numbers show a mortality rate of 31.8 people per 100,000 inhabitants. The level of pollution in São Paulo city, for instance, is around 60% above the World Health Organization target (Barassa et al., 2020).

The city of Shenzhen/China has more than 12 million inhabitants, a population similar to the São Paulo city. Knowing as Chinese Silicon Valley because it has been an important economic hub since 1970, Shenzhen is reference using electric vehicles in its public transport system. It is fully electrified and is composed of 16 thousand of buses (Summit Mobilidade Urbana, 2020).

Due to being very similar to the São Paulo city, both in terms of population and bus fleet, Shenzhen is a good parameter for comparison. It is estimated that the electrification of the bus fleet saves 300 million tons of fuel and avoids the emission of more than 1 million tons of CO_2 into the atmosphere. What differentiates Brazil and China are the tax incentives given to companies that adopt less polluting modes and the government investment in research and development (Summit Mobilidade Urbana, 2020).

In South America, Santiago (Chile) is a model and has 2000 electric buses in its fleet, or 26.93% of the total. Bogota, Colombia has 1486 electric buses in its fleet or 5.38% of the total. On the other hand, in São Paulo, the electric buses represent less than 2% of the fleet (E-Bus Radar, 2023).

4.2 São Paulo actions

São Paulo signed the letter of commitment of the C40 group of large cities for climate leadership to achieve zero carbon emissions by 2050. Therefore, São Paulo established the PlanClima/SP which proposes actions to reduce the use of transport, promote active mobility, and zero gas emissions. Moreover, the plan proposes increasing the adoption of renewable energy sources to replace fossil fuels in transport and the establishment of the COMFROTA-SP (*Comitê Gestor do Programa de Acompanhamento da Substituiçao de Frota for Alternativas Mais Limpas*) which proposes the use of less polluting technology vehicles in the public transport system fleet (Prefeitura da Cidade de São Paulo, 2021; SPTrans, 2020; SPTrans, 2023).

In November 2021, the State Government and the city of São Paulo announced a project to requalify and expand transport corridors, including BRTs (Bus Rapid Transit) totaling 95 km of new roads and 30 km of requalification of existing corridors. In addition, the project involves the construction of four new terminals that will be operated with electric buses, a reduction in the ICMS (*Imposto Sobre Circulaçao de Mercadorias e Serviços*), and the increase of the electric bus fleet to around 2,500 buses by 2024 (Bazani, 2021).

However, Christovam (2020) pointed out that since 1970 there are discussions for the use of alternative fuels in the São Paulo bus fleet but none of them were implemented. Complementary to the SISTRAN plan that proposed the increase of the trolleybus fleet, had the use of methane gas in the bus fleet in 1984 and attempts to use natural gas in the fleet in 1991.

4.3 The adoption of electric buses

Electric vehicles have already proven to have an operating cost lower or equal to combustion vehicles (Vasconcelos, 2015). Vasconcelos (2020) also found in his studies carried out in the Rio de Janeiro city, an advantage in replacing combustion vehicles with electric ones. In addition, the studies presented the social benefits of a reduction in expenses incurred in the health system with a reduction in the emission of polluting gases by the fleet.

Silva (2020) found in his studies in Brasilia an improvement in efficiency with the hybridization and electrification of buses. As electric buses have lower maintenance costs and a reduction in energy consumption and pollutant emissions, the authors stated that these positive results support the need for policies encouraging the use of electrical technology.

Nevertheless, Figueiredo (2021) stated that the panorama of public transport systems by bus is concerning and is in a negative cycle, with a sharp drop in demand, constant increase in fares, a drop in the quality of the service offered, and the bankruptcy of operating companies, putting in doubt the continuation of services. Moreover, even the electric buses being more economical ends up being a contrast with the situation of failure of the transport systems.

Regarding the Industry to produce the electric transport vehicles Vaz, Barros, and Castro (2015), explained that Brazil has a local capacity to manufacture hybrid buses and electric buses, and even with financing, sales do not take off due to the urban transport policy. In most cases, the policy is municipal and vehicle purchases are carried out by operators who also profit from the resale of used buses demonstrating little interest in electric vehicles. This situation is corroborated by the *Associaçao Nacional das Empresas de Transportes Urbanos* (NTU) which stated that the resale of used buses in the main Brazilian municipalities is part of the business of public transport operators and impacts costs and fares (NTU, 2018).

For operators, there is uncertainty about the value of reselling electric and hybrid buses to other markets. There are doubts about the useful life of the vehicles and the need for infrastructure for operations (Parallel overhead lines if it is a trolleybus or a charging station structure if it is a battery) (Vaz et al., 2015). NTU understands that changes in supply technology can represent a difficulty that must be considered by the operator (NTU, 2018).

As electric vehicles also tend to be more expensive, they make municipalities afraid that the adoption of electric or hybrid buses will lead to the need for higher tariffs or greater subsidies for operations (Vaz et al., 2015). Christovam (2020) established that the cost of the operation's infrastructure should be considered and who should be responsible for it. Trolleybuses, for instance, depending on the power supply network, contact lines, rectifier and traction substations to operate. On the other hand, battery-powered vehicles depend on the autonomy of the batteries, the impact of recharge time (in normal or fast charging conditions), not to mention the durability and disposal of batteries at the end of their useful life.

Ferreira and Machado (2020) reported that the estimated useful life of electric buses should be higher than that of diesel buses. However, the uncertainty of the resale values of the used electric bus connected to the performance of the batteries - after the end of their useful life - is not fully known as a problem. Nevertheless, there are alternatives such as battery leasing and extended warranty contracts transferring the risk to the bus or battery manufacturer.

Albuquerque et al. (2019) calculated the TCO (Total cost of ownership) to São Paulo fleet the vehicle procurement cost is high and the value of the battery reaches 60% of the value of the vehicle, this value can be amortized by leasing the batteries, but with a lower operational cost saving is 7% (considering 10 years) with electric vehicles can reach up to 12% (considering 20 years). These fleet cost analysis studies are important information for defining business models, including looking for financial resources including public subsidies.

Eventually, we can infer that to replace the energy matrix, there must be a government initiative, solidly based, a responsible strategic plan, with a clear beginning, middle, and end under a permanent evaluation for the success of the replacement project (Christovam, 2020).

In the fourth step of the research, we discuss based on the literature the issues in the adoption of electric bus systems. Finally, we the last step we compared the costs of electric and combustion engine vehicles in the context of the MASP area.

4.4 Comparison between the operation of electric and combustion buses

Saura Neto (2018) presented a cost comparison of alternative energy alternatives to diesel for a Padron vehicle in São Paulo. This comparison is shown in Table 2.

Table 2 – Comparison between the operation of Electric and Combustion buses

Technology	Consumption (Unit/km)	Fuel Cost (R$/km)	Relative Comparison
Battery-Electric Buses	1.260 kWh/km	0.53	32.0%
Trolleybus	2.290 Kwh/km	1.07	64.3%
Hybrid	0.389 l/km	1.16	70.2%
Natural Gas	0.794 m^3/km	1.54	93.0%
Diesel	0.556 l/km	1.66	100%

Source: Adapted from Saura Neto (2018)

It is possible to verify in Table 2 an advantage in energy consumption per kilometer of electric vehicles over diesel and natural gas vehicles with the advantage of not producing polluting gases followed by the hybrid.

The lower operational cost presented is regarding battery-electric buses. They represent a good operational performance proved by the operational feasibility of Battery Electric Buses at scale in the transport system (SPTrans, 2023).

However, the electrification of the fleet with battery-powered buses faces some problems: the current bus garages will have to undergo changes in their layout and gain covers for the safe installation of chargers, floor insulation, and the need for new specialized employees (Nespoli et. al., 2023; Petrocilo & Pescarini, 2024).

In addition to these problems, the current electrical infrastructure does not support the volume of chargers that must be used simultaneously, resulting in the need for new high-voltage substations that should increase implementation costs, generating disagreements between who should assume the costs of these modifications, city hall, bus companies, or the electricity company responsible for the city (Nespoli et. al., 2023; Petrocilo & Pescarini, 2024).

The second option is trolleybuses. In 2022 the trolleybus operation of São Paulo city had 99% energy available. This number is within the established standard. The equipment is reliable with widely used components. Moreover, the technology is already being developed, tested, and available in the Brazilian market. It is one of the most suitable options in environmental terms (SPTrans, 2023). However, one of the points to be considered according to Saura Neto (2018) is the cost of the catenary systems. Macedo (2017) found the value of R$ 1,400,000.00/km and the cost of R$ 1,100,000.00 for each necessary substation.

As for trolleybuses, they are not "synonymous with the past", even being less flexible than BEBs because they depend on the operating infrastructure (substations and parallel overhead lines) and may have batteries that can facilitate a maneuver in case of disconnection from the network and can be an important role in achieving the goal of reducing greenhouse gas emissions as they already have a consolidated technology compared to other technologies and even BEBs (Bazani, 2019).

Another version is a hybrid Trolleybus, as in the "Silver Line" in Boston – the USA, which increases the flexibility of its use. In Europe, trolleybuses are considered important for reducing gas emissions in several countries (Wołek et al., 2021). Saura Neto (2018) clarified that the advantages of the Trolleybuses are the established and 100% clean technology. However, the low operational flexibility due to the need for the area network, high investment in electrical infrastructure, and a higher maintenance and operation cost when considering the aerial network is something that must be considered.

We can infer that due to the initial cost of infrastructure, trolleybuses are not competitive with diesel buses but the use of clean sources in the production of electricity increases the advantage of trolleybuses and battery-powered vehicles as they will be environmentally, socially, and ecologically friendly (Mathieu, 2018; Wolek et al., 2021).

5. Conclusions

This study showed that São Paulo city is making efforts to implement a fleet of buses powered by electricity. However, the goals of expanding a fleet of "cleaner" buses have not been met. By 2030 alternative fuels will contribute to the reduction of gas emissions, but by 2050 there is a lot of uncertainty regarding reaching zero-emission targets.

Electromobility seems to be an interesting approach to reducing GHG emissions. However, the costs of implementation and maintenance, the competition with the Diesel vehicle industry, and the lack of government support and interest by the operators have been impacting the low adoption in the MASP area. And these facts are reflected over the country.

It is suggested as future studies, a survey of the underutilization of the trolleybus network in MASP, the feasibility of reactivating some stretches, and making a comparison with Battery Electric Buses (BEBs) vehicles be carried out.

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