PROMOB-e

International Evaluation of Public Policies for Electromobility in Urban Fleets

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Study prepared by the International Council on Clean Transportation (ICCT) requested by GIZ (German Agency for International Cooperation) and the Ministry of Industry, Foreign Trade and Services (MDIC).

Authors:
Peter Slowik
Carmen Araujo
Tim Dallmann
Cristiano Façanha

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FEDERATIVE REPUBLIC OF BRAZIL

Presidency of the Republic
Michel Temer

Ministry of Industry, Foreign Trade and Services
Marcos Jorge de Lima

Secretariat of Industrial Development and Competitiveness
Igor Nogueira Calvet

Director of the Department of Industries for Mobility and Logistic – DEMOB
Margarete Gandini

Technical Support
Cooperação Alemã para o Desenvolvimento Sustentável por meio da Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

National Director
Michael Rosenauer

Project Coordinator
Jens Giersdorf

COORDINATION AND EXECUTION

Coordination and operation team
Igor Calvet, Margarete Gandini, Ricardo Zomer, Gustavo Victer, Thomas Caldellas (MDIC), Bruno Carvalho, Fernando Fontes, Jens Giersdorf e Marcos Costa (GIZ).

Auhtors
Peter Slowik, Carmen Araujo, Tim Dallmann e Cristiano Façanha

Technical coordination
Cristiano Façanha and Marcos Costa

Technical review
Marcos Costa (GIZ)
Bruno Carvalho (GIZ)
Ricardo Zomer (MDIC)

Text review and translation
Ana Terra

Cover and graphical project
João Neves

Layout
Barbara Miranda

PUBLISEHD BY

Projeto Sistemas de Propulsão Eficiente – PROMOB-e (Projeto de Cooperação Técnica bilateral entre a Secretaria de Desenvolvimento e Competitividade Industrial – SDCI/MDIC e a Cooperação Alemã para o Desenvolvimento Sustentável (GIZ)

CONTACTS

SDCI/Ministério da Indústria, Comércio Exterior e Serviços
Esplanada dos Ministérios BL J - Zona Cívico-Administrativa, CEP: 70053-900, Brasília - DF, Brasil.
+55 (61) 2027 – 7293
www.mdic.gov.br

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
SCN Quadra 1 Bloco C Sala 1501 – 15° andar Ed. Brasília Trade Center, CEP: 70711-902, Brasília-DF, Brasil.
+55 (61) 2101-2170
www.giz.de/brasil

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For additional information:
International Council on Clean Transportation 1225 I Street NW Suite 900
Washington, DC 20005 USA
communications@theicct.org | www.theicct.org | @TheICCT

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ABDI	Brazilian Industrial Development Agency
Abeifa	Brazilian Association of Motor Vehicle Importing and Manufacturing Companies
ABNT	Brazilian Association of Technical Standards
ABVE	Brazilian Association of Electric Vehicles
AEA	Brazilian Association of Automotive Engineering
Aneel	Brazilian Electricity Regulatory Agency
ANP	National Agency of Petroleum, Natural Gas and Biofuels
ANTP	National Association for Public Transport
BEB	Battery electric bus
BEV	Battery electric vehicle
BNDES	National Bank of Economic and Social Development
Camex	Foreign Trade Chamber
CARB	California Air Resources Board
Cetesb	São Paulo State Environmental Company
CNPE	National Energy Policy Council
CO	Carbon monoxide
CO_2	Carbon dioxide
Denatran	National Transit Department
EMTU	Metropolitan Urban Transportation Company of São Paulo
EPE	Energy Research Company
VE	Electric vehicle
EVSE	Electric vehicle supply equipment
FCEB	Fuel cell electric bus
GEE	Greenhouse gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GQA	Air Quality Management
HC	Hydrocarbons
HEB	Hybrid electric bus
HOV	High-occupancy vehicle
Ibama	Brazilian Institute of the Environment and Renewable Natural Resources
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IGES	Institute for Global Environmental Strategies
Inmetro	National Institute of Metrology, Standardization and Industrial Quality
INTD	Intended nationally determined contribution
IPI	Tax on Industrialized Products
ISO	International Organization for Standardization
LCFS	Low-Carbon Fuel Standard
Mcid	Ministry of Cities
MCTIC	Ministry of Science, Technology, Innovation and Communications
MDIC	Ministry of Industry, Foreign Trade and Services
MMA	Ministry of the Environment
MME	Ministry of Mines and Energy
MWh	Megawatt hour
NDC	Nationally determined contribution
NMHC	Non-methane hydrocarbon
NOx	Nitrogen oxides
NTU	National Association of Urban Transportation Companies
O_3	Tropospheric ozone
PDE	Ten-Year Energy Plan

Petrobras	Brazilian Petroleum Corporation
PHEV	Plug-in hybrid electric vehicles
MP	Particulate matter
Proconve	Program for the Control of Air Pollution by Motor Vehicles
R&D	Research and development
RMSP	São Paulo Metropolitan region
SAE	Society of Mobility Engineers
SIN	National Interconnected System
Sindipeças	National Union of the Motor Vehicle Components Industry
SPTrans	São Paulo Transporte S.A.
TCO	Total cost of ownership
tep	Tonne of oil equivalent
EPA	United States Environmental Protection Agency
UNFCCC	United Nations Framework Convention on Climate Change
V2G	Vehicle to grid
VAT	Value-added tax
VKT	Vehicle kilometers traveled
WHO	World Health Organization
WTW	Well-to-wheel
ZeEUS	Zero Emission Urban Bus System
ZEV	Zero Emission Vehicle

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EXECUTIVE SUMMARY

Transportation electrification is commonly seen as a key measure to reduce greenhouse gas (GHG) emissions and mitigate climate change. Many urban environments are also grappling with severe air pollution and the resulting threats to public health, and cities are increasingly evaluating and implementing robust policies to encourage the adoption of electric vehicles (EVs). Governments are also interested in the economic, industrial, and employment benefits from local development and manufacturing of emerging technologies such as EVs and their supporting infrastructure. Research shows that countries that adopt stringent environmental standards and a coordinated strategy for electromobility secure early-mover advantage for their firms, leading to the conditions that allow for industrial competitiveness in international markets.

SALES OF EVS ARE INCREASING SUBSTANTIALLY IN KEY VEHICLE MARKETS

Efforts to support the EV market are beginning to take hold, and the early market steadily grows each year. Figure ES-1 illustrates the dramatic growth in annual global light-duty EV sales since 2010, with ten markets accounting for over 90% of total global sales. In 2017, EV sales surpassed 1.2 million units, with China representing approximately half. Cumulative global sales since 2010 surpassed 3 million in November 2017 (ZEV Alliance, 2017). The market for plug-in and electric vehicles in Brazil is, as of yet, nearly non-existent, with less than 200 cumulative new EVs in the 2010-2017 period.

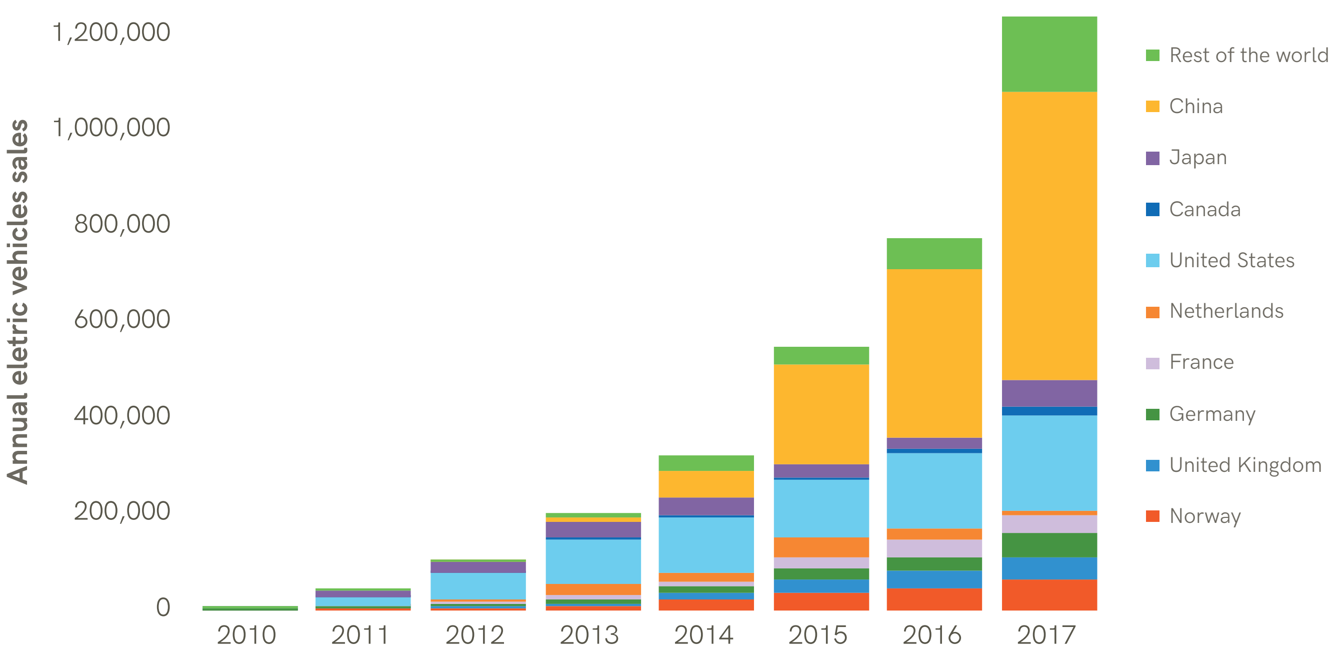

Figure ES-1 | **Annual global EV sales from 2010 through 2017**[1]

Electric buses, while smaller in volume, have also experienced high growth rates. Global electric bus stock more than doubled from 170,000 in 2015 to 345,000 in 2016 (IEA, 2017). More than 99% of the global electric bus stock is in China, with rapid procurement driven largely by urban pollution and supported with strong government financial incentives, infrastructure, and industrial policy. Electric buses in the United States and Europe are rapidly reaching commercial deployment. In Brazil, there are about 296 electric trolley buses in circulation in São Paulo.

[1] Numbers include plug-in hybrid, battery electric, and fuel cell vehicles.

EV UPTAKE LARGELY FOLLOWS THE LEVEL OF GOVERNMENT ACTION AND SUPPORT

Research on international experiences shows that government action – vehicle and fuel regulations, consumer incentives, charging infrastructure programs, planning, and local policies and initiatives – help to overcome barriers related to EV model availability, higher upfront costs, functional electric range and range anxiety, and overall lack of awareness and understanding. As a result, EV uptake varies substantially, largely in parallel with the level of government action and support policies at the national, provincial, and local levels. In the early years when EV production is low, automakers have tended to focus their EV marketing and deployment efforts in regions with the most supportive policies in place (Lutsey, 2015). Table ES-1 summarizes the EV promotion actions considered in this evaluation and their implementation in major markets, which account for over 90% of cumulative global EV sales.

Although the data in the table is specific to light-duty vehicles, the policies are also applicable for public and private urban fleets, which are the focus of this study. Many of the policies in place internationally are supporting the electrification of passenger cars, commercial vehicles, and buses; however, depending on the government decision, some policies only target a specific vehicle type. Programs that currently limit vehicle eligibility could be modified or extended to include the broader vehicle market.

Local support policies in leading cities are carefully tailored to fit local contexts. For example, major cities in China, suffering from heavy congestion and air pollution, have implemented strict vehicle registration quotas. As a result, exempting EVs from this quota makes them very attractive to residents and sends a strong signal that electric mobility is the future. Additionally, some of these cities in China allow electric cars to drive even on days when internal combustion engines are banned from circulation. In California, congestion in major cities makes access to high-occupancy vehicle lanes on freeways a valuable perk.

Similarly, electric buses are being deployed where supporting policies have been put in place. Around 99% of the global electric bus fleet on roads today is in China. Driven by the urgent need for clean air, the central and local governments have supported the electric bus transition with a strong policy vision and procurement targets, significant financial purchase incentives, charging infrastructure support, and friendly industrial policy for local bus manufacturing. Between 2009 and 2017, Shenzhen converted its entire fleet of 16,000 buses to electric, a major success story that is ripe for further evaluation and understanding of the key lessons learned and best practice implementation strategies that can be shared more broadly.

Table ES-1. **Public EV promotion actions in selected areas**

Area	Approximate 2017 sales and sales shares		Clean vehicle and fuel regulations			Consumer incentives							Charging infrastructure				Planning, policy, and other promotions					
			Clean vehicle mandates	Fuel efficiency standards	Clean fuel standards that credit electricity	Subsidies for vehicle purchase	Tax exemptions for vehicle purchase	Exemption from annual fees	Preferential lane access	Preferential parking access	Discounted or free charging	Financing programs	Standard protocols for EVSE	EVSE incentives or funding	Direct deployment	EV-ready building codes	Procurement targets	Electric-mobility strategy	Outreach and awareness	Demonstration projects	Fleet initiatives	Low-emission vehicle zones
Canada	19,000	0.9%	/	X	/	/					/			X	/	/	X	/	/	/	/	
China	600,200	2.1%	X	X		X	X	X		/	/			X	/	/	X	X	/	X	X	/
France	36,900	1.8%		X		X	X	X		/				X	X	X	X	/	/	/	X	/
Germany	53,500	1.6%		X		X	X	X	/	/	X	/	X	X	X		X	X	X	X	X	
Japan	55,900	1.1%		X		X	X	X			X			X	X	/	X	X	/	/	X	
Netherlands	9,200	2.2%		X		/	X	X	X	/	X		X	X	X		X	X	X	X	X	/
Norway	62,200	39.2%		X			X	X	X	/	X			X	X	/	X	X	X	/	X	/
UK	48,400	1.9%		X		X	X	X		/	/	X		X	X	/	X	X	X	X	X	/
USA (excl. California)	96,000	0.7%	/	X		X	/	/	/	/	/		/	X	/	/	X	X	/	/	/	
California	96,500	4.9%	X	X	X	X			X	/	X	X	X	X	X	/	X	X	X	X	X	

x denotes national program and / means smaller local or regional program.
Data retrieved from Hall and Lutsey (2017a, 2017b), Hall et al. (2017a, 2017b), Jin and Slowik (2017), Lutsey (2015), Slowik and Lutsey (2017), Tietge et al. (2016), Yang et al. (2016). 2017 sales and sales shares based on CNCDA (2018) and EAFO (2018).

NATIONAL EXPERIENCE TO ENCOURAGE ELECTROMOBILITY HAS BEEN INSUFFICIENT WHEN COMPARED TO INTERNATIONAL BEST PRACTICESS

Brazil has not yet adopted the comprehensive EV promotion policies that are being implemented in the leading electric markets depicted in Figure ES-1 and Table ES-1 above. Brazil's efficiency targets for light-duty vehicles are insufficient to encourage increased EV model availability to launch the EV market. There are no substantial upfront incentives to promote consumer EV sales. The regulations and incentives in China, Europe, and the United States have made these the dominant EV markets around the world. In addition, there is no charging infrastructure plan in Brazil to ensure home charging or to instill broader market confidence with public charging ecosystem. Finally, Brazil does not have planning, promotional activities, and awareness measures comparable to those in major international EV growth markets.

To embrace international best practices, Brazil should build from existing projects to develop policies to overcome EV barriers. A focus on urban buses makes sense in the near and medium term because of Brazil's reliance on diesel, which would leverage the benefits from electrification together with investments in urban mobility. First, Brazil should implement stronger efficiency targets and expand them to buses and trucks to ensure EV models are deployed as they approach cost parity in the approximate 2025 timeframe. Second, with respect to the upfront cost differential between electric and combustion vehicles, Brazil could modify import and registration taxes to exempt or incentivize plug-in and battery electric vehicles. In the case of urban buses, new financing models that include battery leasing and possibly charging infrastructure (e.g., photovoltaic panels) should be evaluated. Third, regarding charging infrastructure, an important starting point for Brazil would be to offer tax exemptions and cost-share charging infrastructure. Finally, to begin to expand consumer awareness and understanding, Brazil could invest in public campaigns that emphasize the benefits of electrification, in particular with respect to public buses.

All of these actions would gain from coordinated action to overcome technical, economic, and infrastructure barriers. However, Brazil has so far focused on isolated initiatives, mostly involving demonstration projects, research studies, and tax incentives, still with modest or unclear results. There are no coordinated policies or initiatives to promote electromobility in the country. Near- and long-term national energy plans would better signal vehicle electrification as a viable alternative to energy efficiency and decarbonization targets. They could also provide a basis for better articulation across multiple technology research and development (R&D) initiatives. Rota 2030, Brazil's new policy for industrial competitiveness, could represent an opportunity to drive the rhythm of electrification, encouraging coordinated action in R&D, industry investments and leveraging complementary action such as charging infrastructure investments.

Brazil needs to clearly articulate their motivations for electromobility so that they are translated into public policies and implemented as complementary actions and programs. A key lesson learned is that, without clear motivations, as it is currently the case in Brazil, this integration of efforts rarely happens. To contribute to this debate, this study evaluated key motivations for electromobility in Brazil accounting for energy sources in transportation and the power sector in the country. Transport electrification brings significant reductions in emissions of GHGs and local air pollutants, lowers energy consumption due to higher engine efficiency, and promotes energy security, amongst others. Even accounting for a higher participation of biofuels compared to other countries, national energy projections still indicate a predominance of fossil fuels in transport in the short and long term. Additionally, power generation is and will continue to be composed of over 80% renewables, which augments the environmental benefits from electrification. In large cities, large auto fleets will increase by 44% by 2030, and air quality, already above the guidelines from the World Health Organization guidelines for most Brazilian cities, will worsen.

ELECTRIC DRIVE TECHNOLOGIES CAN BE MORE COST-EFFECTIVE

One of the most important considerations when evaluating the potential for electric drive transition is the cost of these alternative technologies relative to conventional combustion engines. Electric drive technologies, such as hybrid electric or battery electric vehicles, require greater capital expenditures for procurement, and, in the case of battery electric vehicles, charging infrastructure. However, these technologies also offer the potential for operational cost savings from, for example, reduced fueling and maintenance costs, which can make them competitive with combustion vehicles when lifetime costs are considered. Thus, a key question for electric drive transitions is the degree to which operational savings offset the higher capital costs associated with these alternative technologies.

This study compared the total cost of ownership (TCO) of electric drive and conventional combustion technologies, using the São Paulo municipal transit fleet as a case study to explore the costs of electric drive bus transitions in Brazil. The evaluation included lifetime costs and emissions of black carbon and GHGs from conventional diesel, biodiesel, diesel hybrid electric, battery electric, and fuel cell electric buses. The analysis found life-cycle costs for diesel hybrid electric and battery electric bus technologies to be competitive with those for P7 (current regulatory standard for vehicle emissions in Brazil) diesel buses for most of the bus types in the São Paulo fleet. Figure ES-2 illustrates the differences in TCO for a Padron LE bus, one of the most typical bus configurations in São Paulo.

In addition to lower costs, a transition to electric buses in São Paulo would result in significant reduction of GHG and black carbon emissions. Accounting for the monetized climate and health damage (not included in the results in Figure ES-2), diesel hybrid electric and battery electric buses would reduce TCO by 10% and 27%, respectively. It is important to emphasize that these results reflect current costs, which will likely decrease substantially in future years as technology improves and production volumes increase. In contrast, transitions to a biodiesel bus fleet are estimated to be slightly more costly than conventional diesel buses, and could also significantly increase well-to-wheel climate emissions due to relatively high land use emissions assumed in this analysis for soy-based biodiesel.

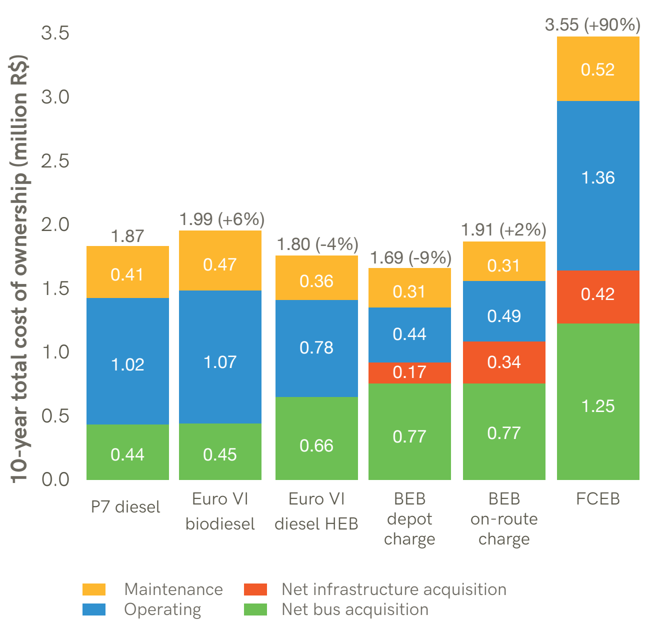

Figure ES-2 | **Total cost of ownership over 10 years for conventional and alternative bus technology in São Paulo**[2]

THE ELECTRIFICATION OF URBAN BUSES IS A NEAR-TERM PRIORITY

While most of the international media attention focuses on electric passenger cars, a more adequate focus for Brazil in the near term is the electrification of urban buses, which would combine the benefits from electrification with investments in urban mobility.

Electric buses would bring a series of environmental improvements, including better urban air quality and public health, less noise, and lower emissions of climate pollutants. The majority of urban buses rely on diesel technology, which represent the lion's share of emissions of particulate matter and nitrogen oxides, two of the most important air pollutants contributing to worsen public health. The replacement of diesel buses with electric buses would eliminate tailpipe emissions while improving noise pollution. In addition, the replacement of diesel with electricity that is roughly 80% renewable would bring sizeable climate benefits.

In addition to environmental benefits, investments in electric urban buses align well with government incentives towards urban mobility and the promotion of public transit over individual motorization. Urban mobility has brought to the forefront increasingly complex problems related to the uncontrolled growth of cities, and vehicle technology should not be dissociated from the main mobility principles and guidelines. Based on guidelines of the National Policy on Urban Mobility, in addition to prioritizing non motorized and public transportation over motorized individual transportation, scientific and technology development and the use of renewable and cleaner energy sources must be encouraged.

The comparative cost analyses of bus technologies presented in this study, with advantages for electric buses, reinforce the opportunities for electrification and strengthen their business case. As Brazil is already in a position to migrate to this niche more speedly, considering the cost and production capacity advantages, the efforts to overcome barriers would bring innumerable benefits. Lower operating and total costs may reduce tariffs, and leverage the nation's industrial competitiveness position for new technologies.

Brazil can leverage São Paulo's commitment to zero

[2] Data labels indicate contributions of individual cost components to TCO estimates. Percentages show change in TCO relative to the baseline P7 diesel technology. Acquisition costs include down payment and loan payments minus any bus resale value at the end of the ownership term.

emission buses. With over 14,000 buses transporting 9.5 million passengers per day, São Paulo's experience could be replicated in other cities, especially with support to overcoming barriers through better coordinated public policies. Other Brazilian cities could adopt emission reduction targets for their public transportation service concession contracts, further increasing the demand for electric buses.

BRAZIL CAN BE PART OF A GLOBAL TRANSITION TO ELECTROMOBILITY

Regions across North America, Europe, China, and elsewhere are developing long-term regulatory policy, implementing incentives, and deploying charging infrastructure to support the EV market. Markets in Europe and China, especially, are experimenting with similar and even bolder policies that explicitly promote EVs. Every region including Brazil can learn from these experiences regarding the identification of which measures work best and which can be improved. Expanding the application of best-practice promotion policies will continue to accelerate the transition to a global EV fleet.

A major challenge for electrification in Brazil is to go beyond current solutions for GHG mitigation and energy security, currently focused on biofuels, and advance toward complementary alternatives. Biofuels, a praiseworthy solution for Brazil considering its agricultural vocation, do not improve urban air quality, nor do they reduce long-term GHG emissions considering the projected fleet growth. In the case of biodiesel, the limitations are stronger due to its indirect land use changes that can offset its climate benefits, and potential restrictions on production capacity. Along a pathway towards transportation decarbonization, vehicle electrification would complement biofuels, with added gains in energy efficiency that cannot be obtained with conventional technologies. The Brazilian electricity generation matrix, strongly based on renewable energy even in future projections, would leverage the benefits from electromobility.

It is important to enact policies that help remove the barriers to model availability, higher upfront costs, functional electric range and range anxiety, and overall lack of awareness and understanding. A system of vehicle and fuel regulations, consumer incentives, charging infrastructure programs, planning, and local policies and initiatives are a proven path overcoming EV adoption barriers and driving adoption. This would bring benefits in terms not only of energy efficiency and emissions but also of industrial competitiveness. Over 75% of global EV sales are manufactured in the same region in which they are sold. Brazil has an opportunity to learn from leading global examples and lead the growing South American market. Setting clear volume targets and providing financial incentives ultimately have vested governments and companies in developing an EV market and domestic manufacturing base (Lutsey et al., 2018).

The first challenge is to position vehicle electrification, particularly for public transportation, and to internalize it as a public policy, which would lead to a natural coordination of efforts to accelerate its introduction. The various key actors would have a unique understanding and move in the same direction. The development of knowledge, now dispersed across research centers and universities, would be channeled into common work streams, thus improving final results. Additional investments would be made by the private sector based on firmer policy signals, scale gains would be achieved, and cost barriers would be reduced. The automotive industrial policy, currently under discussion, would clearly follow such policy signals, increasing the competitive advantages for Brazil vis-à-vis opportunities in international markets. Energy plans would incorporate consistent advances towards electrification. Additional efforts to improve electric bus technology and operations would intensify, with positive results.

The international experiences to stimulate electromobility have indicated a wide range of alternatives to be considered in the Brazilian context. Again, these experiences can serve as inspiration for actions to be taken once there is a clear policy path to follow. Subsequent steps will naturally arise from coordinated efforts, and mechanisms for monitoring and evaluation of results may require adjustments to the routes adopted as an evolutionary process of public policies.

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INTERNATIONAL EVALUATION OF ELECTROMOBILITY POLICIES

This evaluation of international electric mobility public policies is focused on light-duty passenger vehicles including public and private fleets, buses, and urban delivery vehicles. The geographic scope includes the major markets in North America, Europe, and Asia, and the analysis highlights emerging developments in India when relevant. Although preliminary policies for public electric buses are being discussed in select markets in South America, including Chile and Colombia, they are in relatively early stages of development and thus not included in this evaluation. This chapter provides an in-depth look at the various public policies and initiatives that are supporting electric mobility development, divided in the four categories listed in Table 1-1.

Table 1-1 | **Government promotion actions for EVs**

Category	Action
Clean vehicle and fuel regulations	• Clean vehicle mandates • Fuel efficiency standards • Clean fuel standards that credit electricity
Consumer incentives	• Vehicle purchase incentives (subsidies and tax exemptions) • Exemptions from annual fees • Preferential lane access • Preferential parking access • Discounted/free charging • Financing programs
Charging infrastructure	• Standard protocols for EVSE • EVSE incentives or funding • Direct deployment • EV-ready building codes
Planning, policy, and other promotions	• Procurement targets • Electric-mobility strategy • Outreach and awareness • Demonstration projects • Fleet initiatives • Low-emission vehicle zones

Some of the public policies and actions included in this assessment are designed to encourage the adoption of privately-owned electric cars. However, they are often highly applicable to other ownership models (privately-owned, public fleets, private fleets) and vehicle types (passenger cars, light commercial vehicles, buses). In theory, these policies could be modified or extended to include the broader market.

The following sections analyze the various actions and their potential impacts on electric vehicle (EV) adoption, according to the four categories indicated in Table 1-1, namely clean vehicle and fuel regulations; consumer incentives; charging infrastructure; and planning, policy, and other promotions. The last section in this chapter summarizes the findings from this analysis and provides several anecdotes. The evaluation includes a discussion of key factors for success, best practice elements, and potential challenges, when applicable.

CLEAN VEHICLE AND FUEL REGULATIONS

This section summarizes the clean vehicle and fuel regulations supporting EV adoption around the world. The actions assessed here include clean vehicle mandates, fuel efficiency standards, and clean fuel standards.

CLEAN VEHICLE MANDATES

The major markets of California and China have introduced sales quotas for EVs. The programs incrementally require greater EV sales over time by placing annual mandatory EV sales requirements for auto manufacturers. The programs significantly boost EV markets and push automakers for greater EV model availability and greater marketing efforts (NESCAUM, 2016, 2017). Consumer vehicle make and model preferences vary widely, so the availability of a range of EV models is a key factor in the broader adoption of EVs (see, e.g., NRC 2015).

California's Zero Emission Vehicle (ZEV) regulation requires 8% of new vehicle sales to be electric in 2025 (CARB, 2017a). The state accounts for half of the United States EV market, underscoring the major impact of direct requirements for EVs (Lutsey, 2017). China's 2017 New Energy Vehicle mandate policy is similar to California's program and requires approximately 4% of new vehicle sales to be electric in 2020 (Cui, 2018). The programs are globally unique by mandating EV deployment with enforceable fines (Lutsey, 2015). With China as the world's largest automobile market, the New Energy Vehicle policy is a global milestone that will surely accelerate transportation electrification globally. Similar yet smaller programs include Québec's ZEV standard, which came into effect in January 2018 (MDDELCC, 2018).

Only light-duty passenger vehicles are included under the mandate programs in China, California, and Québec. However, the policy in theory could extend to other vehicle types. California for example has proposed the Innovative Clean Transit rule, which would phase in zero emission bus procurement requirements for municipal transit agencies in the state (CARB, 2017b). As currently drafted, the rule would require all bus purchases to be zero-emission by 2029 (CARB, 2017b). Such policies are expected to significantly contribute to urban air pollution reduction while spurring economic investment, innovation, and job growth in clean vehicle technology in California. Similar policies could be introduced or extended to include requirements for public or private fleets, urban delivery vehicles, or other vehicle modes.

At the local level, London has introduced licensing requirements for new taxis starting 2018. All taxis seeking initial licensing must be zero-emission capable (i.e., plug-in hybrid electric or all-electric). In 2020, similar requirements extending to other for-hire vehicle fleets phase in (Transport for London, 2018). The policies create major disincentives for fleets that do not comply with the emission standards by establishing a daily charge. The announcements have sparked actions from the private for-hire sector as a result. Uber, for example, is exploring paths to integrate fully EVs into its platform, citing forthcoming regulations regarding tailpipe emissions as a key motivation (Lewis-Jones & Roberts, 2017).

FUEL EFFICIENCY STANDARDS

Most major vehicle markets have established fuel economy or greenhouse gas (GHG) emissions standards for passenger vehicles and light commercial vehicles. Such regulations reflect the commitment of governments to improve global environmental health, ensure energy security, mitigate climate change, protect consumers' economic interests, and drive technological innovation (Yang and Bandivadekar, 2017). The United States is among the leading markets with regard to the stringency of the emission standards adopted. To some extent, the U.S. regulations are promoting greater EV uptake.

U.S. Environmental Protection Agency (EPA), for example, estimates that only about 5% of the national new light-duty vehicle sales will need to be plug-in electric to comply with the 54.5 fleet mile-per gallon (163g CO_2-e/mi) target in 2025 (U.S. EPA, 2016). Figure 1-1 shows the U.S. fleet-wide CO_2 target (left y-axis) by year (x-axis), and the estimated EV sales share as a result of the standards (right y-axis). The U.S. EPA's estimate (5% by 2025) is shown, along with a hypothetical extension of the standards into 2030, at 4-6% lower CO_2/year. As shown, the EV share increases as a result of more stringent emission standards.

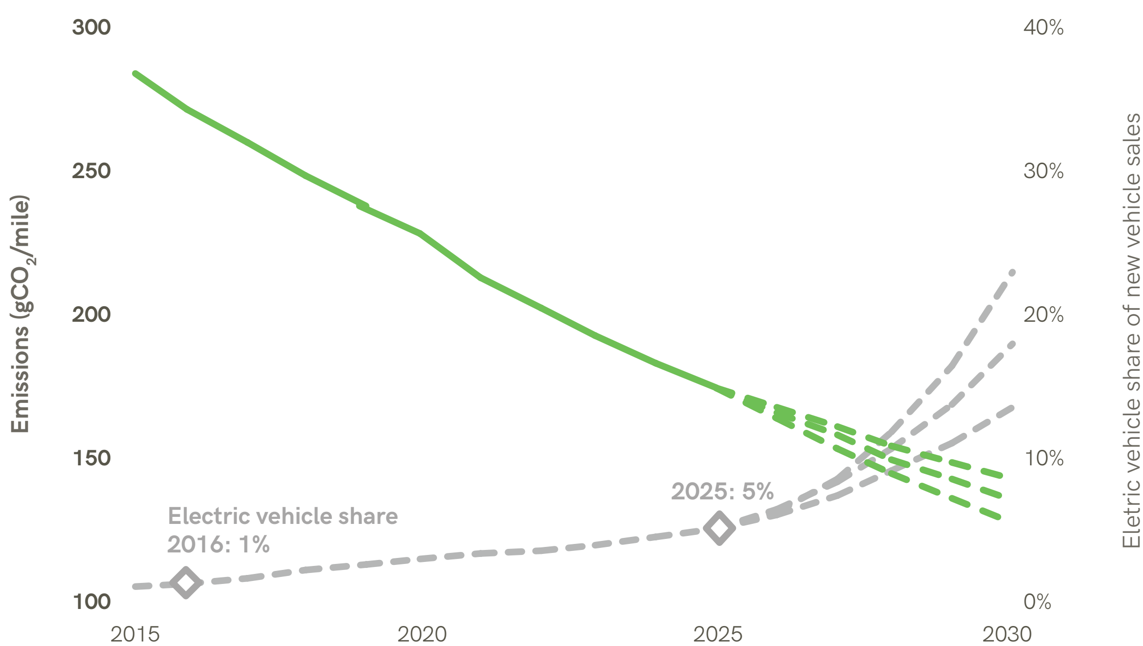

Figure 1-1 | **U.S. light-duty emission standards and estimated EV sales shares (2015-2030)**[3]

Of course, less stringent standards would promote EVs to a smaller extent, putting more pressure on non-regulatory policies to develop the market (Lutsey, 2017). On its website, ICCT (2018) provides a global comparison of the fuel economy or GHG emissions standards for passenger vehicles and light-commercial vehicles.

The European Union first introduced mandatory CO_2 standards for new passenger cars in 2009. Today, the regulations have been finalized to 2020, setting the fleet target to 95gCO_2/km (Mock, 2014). Previous analysis shows that the targets can be met by increasing conventional combustion vehicle efficiencies, thereby requiring zero or a very low market share of EVs (Mock, 2017). However, the regulation includes incentives for EVs, namely by neglecting upstream emissions and allowing super-credits (i.e., counting each vehicle as it if were multiple vehicles). Despite these incentive provisions at the EU level, EV markets vary widely across member states; EVs had a 9.7% share of new-vehicles in the Netherlands, but only a 0.7% share in Germany in 2015 (Mock, 2016). This illustrates the important role of fiscal and other non-regulatory EV incentives in national and local levels (Tietge et al., 2016).

In 2017, the European Commission published its proposed regulation for post-2020 CO_2 targets for cars and light-commercial vans. The proposal includes incentives and the following targets for zero- and low-emission vehicle sales of both cars and light-commercial vans: 15% for 2025-2029 and 30% for 2030 (Dornoff et al., 2018). There are currently no penalties for failing to meet the targets.

Continuing to increase the stringency of fuel efficiency and CO_2 standards will progressively promote more advanced vehicle technologies into the fleet, including EVs. Where EVs receive incentives within the regulatory accounting (e.g., in China, Europe, India, and the U.S.), artificial incentives can partially undermine the short-term benefits of the standards. For example, applying super-credits allows the rest of the vehicle fleet to emit higher levels of emissions or remain at lower miles-per gallon efficiencies which erode the stringency of fuel consumption standards. This is the case in the U.S., Europe, and China. Preventative measures and policies could be implemented to minimize the degradation of the standards as a result of EV incentive provisions (Cui, 2018; Lutsey, 2017).

[3] Based on efficiency technology and cost assessment for U.S. 2025-2030 light-duty vehicles (Lutsey et al., 2016).

CLEAN FUEL STANDARDS THAT CREDIT ELECTRICITY

British Columbia and California have adopted low-carbon fuel policies that incentivize the use of low-carbon transportation fuels, including electricity, and impose deficits for higher-carbon fuels. In California, the Low-Carbon Fuel Standard (LCFS) requires decarbonization of transportation fuels by setting GHG emissions limits and includes provisions to incentivize electricity as a transportation fuel. The program offers a funding mechanism by allowing low-carbon fuel providers to generate credits, thereby assisting EV charging providers. LCFS credits help promote low carbon transportation across many vehicle modes, fuels, and income brackets (CARB, 2018a).

Under the LCFS program, electric utilities are required to pass incentive credits to current or future EV customers. Several utilities (PG&E, LADWP, SMUD, SDG&E) launched consumer rebates (valued at about USD 500-600) in 2017 for EVs or their infrastructure. The program also provides separate credits to local transit agencies that are integrating electric buses, rail, and other low-carbon transit options (CARB, 2018a).

Clean fuels regulations provide strong long-term signals for the incremental decarbonization of transportation fuels. California's program has the dual-benefit of generating direct financial incentives for transportation electrification, and thus is helping to overcome key market barriers related to affordability and charging infrastructure deployment.

Other clean fuel standards currently promote EVs to a lesser degree. The European Union's Fuel Quality Directive, for example, placed a mandatory target for fuel suppliers to reduce life-cycle GHG emissions by 6% for energy supplied for transportation in 2020. Electricity can contribute toward the target (Official Journal of the European Union, 2015), which, however, is expected to be met largely with first-generation biofuels together with upstream emission reductions (Bitnere & Searle, 2017). Continuing to increase the stringency of the standard would do more to promote electrification as a transportation fuel.

Table 1-2 summarizes international clean vehicle and fuel regulations.

Table 1-2 | **International clean vehicle and fuel regulations**

Regulation	Description	Rationale	Typical stake-holder	Implications for EV adop-tion
Clean vehicle mandates	Requires vehicle manufacturers to produce more ZEVs	Commercialize advanced technologies, long-term emission reductions	National or provincial government	Generate major market impact from direct sales requirements and greater availability of EV models
Fuel efficiency standards	Regulations to incrementally improve average vehicle fuel economy	Limit CO_2 emissions and reduce petroleum consumption	National or provincial government	Currently push few EVs into the fleet
Clean fuel standards that credit electricity	Regulations to reduce the carbon intensity of transportation fuels	Reduce emissions and petroleum consumption	National or provincial government	Incentivize electricity as a low-carbon fuel supporting EV and EVSE deployment

CONSUMER INCENTIVES

Consumer fiscal incentives to promote the adoption of EVs are in place in many nations and include vehicle purchase incentives, exemptions from annual fees, preferential lane and parking access, discounted or free charging, and vehicle financing. Such incentives help consumers overcome key cost and convenience barriers, thereby giving impetus to the early EV market while technology costs fall and consumers become familiar with the technology (Slowik & Lutsey, 2016). Numerous studies have shown that purchase and other consumer incentives are linked to EV uptake (Hall & Lutsey, 2017a; Jin et al., 2014; Lutsey et al., 2015, 2016; Mock & Yang, 2014; Slowik & Lutsey, 2017; Tal & Nicholas, 2016; Vergis & Chen, 2014; Vergis et al., 2014; Yang et al., 2016; Zhou et al., 2016, 2017). Many national and subnational governments offer one or more consumer incentives. This section summarizes their implementation across several markets.

VEHICLE PURCHASE INCENTIVES (SUBSIDIES & TAX EXEMPTIONS)

Many governments provide fiscal incentives that reduce the purchase price for EVs. Such incentives fall into two broad categories: subsidies and vehicle tax reductions. Subsidies tend to be relatively transparent and direct, generally with a vehicle-specific dollar value attached. Vehicle tax reductions can be much more variable, opaque, and are dependent on both the tax system and the vehicle specs (Yang et al., 2016).

EV purchase subsidies are implemented at the national and provincial levels, and are available in many regions: Canadian provinces (British Columbia, Ontario, Québec), China Central Government, regions in China (e.g., Beijing, Shenzhen, Shanghai, Hefei, and Hangzhou), France, Germany, India Central Government and some state governments (e.g., Delhi), Japan, Korea, Sweden, the United Kingdom, many U.S. states (including California), and the U.S. federal government (Yang et al., 2016). France's Bonus-Malus feebate system provides a subsidy for EV purchase along with a system of fees for higher-emission vehicles, and thus helps to lock in revenue source durability.

Vehicle purchase tax reductions are most commonly implemented at the national level and on a one-time basis. Many regions have chosen to fully or partially exempt eligible EVs from at least one type of purchase tax. Norway, for example, levies high value-add tax (VAT) and registration tax on vehicles. Battery electric vehicles (BEVs) are fully exempt from both whereas plug-in hybrid electric vehicles (PHEVs) claim partial exemption (Slowik & Lutsey, 2016). Other regions with vehicle purchase tax reductions include China, Denmark, France, Japan, Netherlands, and United Kingdom (Yang et al., 2016).

Urban areas benefit from, and are constrained by, policy at the regional and national level, especially for financial incentives (Hall et al., 2017a). Figure 1-2 shows the value of financial incentives for BEVs and PHEVs (bars, left-axis) in several cities worldwide, as well as their respective sales shares in 2016. As shown, the leading markets in terms of EV sales shares tend to offer substantial fiscal incentives.

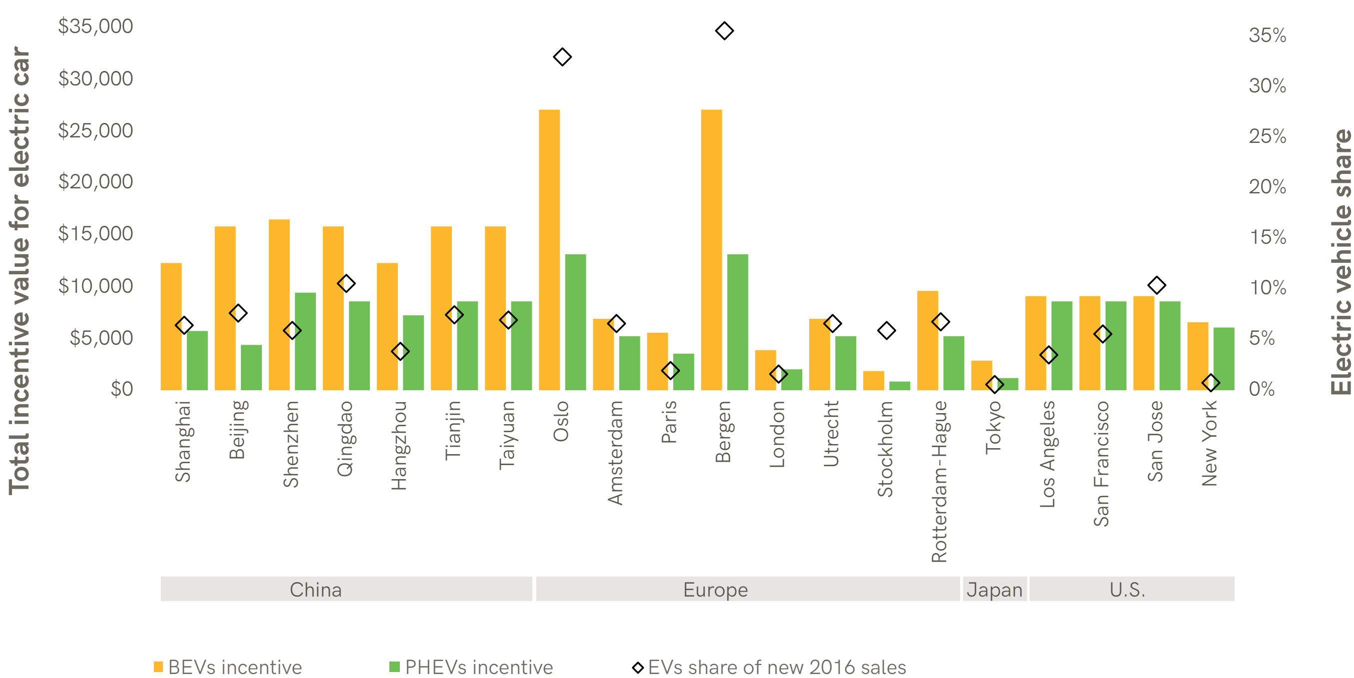

Figure 1-2 | **Incentive value for BEVs and PHEVs and 2016 sales share in major EV markets (Hall et al., 2017a)**

Researchers have studied the relationship between fiscal incentives and EV adoption in more detail. A recent multivariate linear regression analysis of 350 metropolitan areas worldwide identified consumer financial incentives as statistically linked with greater EV uptake (Hall & Lutsey, 2017a). A separate analysis of 200 metropolitan areas in the U.S. also revealed a strong relationship (Slowik & Lutsey, 2017). Research shows that incentives can be optimized to encourage EVs. In general, consumer financial incentives that are substantial in value, available at the point of sale for multiple vehicle and ownership types, crystal clear in value, and locked into place for several years tend to be effective (Yang et al., 2016).

Several anecdotes illustrate the importance of incentives. In the U.S., Georgia state offered an incentive worth USD 5,000, and in 2014 EVs were 3.5% of new vehicle sales (over 4 times the national average). The incentive expired in 2015 and registrations fell by more than 80%, to around 0.7% in 2016 (Slowik & Lutsey, 2017). Major reductions in fiscal incentives had similarly negative market impacts in the Netherlands and Denmark in 2015 and 2016 (Tal & Brown, 2017). In the future, governments would more ideally gradually phase down fiscal incentives while continuing complementary and regulatory policy (Slowik & Lutsey, 2016).

Several jurisdictions provide incentives specifically for fleet procurement. In the U.S., 12 states offered purchasing incentives for public or private fleets, including municipal or state agencies, public transit operators, universities, non-profit organizations, or for-profit corporations (Slowik & Lutsey, 2017). California operates separate incentive programs for electric cars and electric trucks and buses, and recently allocated USD 9.5 million to Porterville Transit for 10 battery electric buses (CARB, 2018a). In the Netherlands, Amsterdam offers €5,000 for electric taxis, company-owned vehicles, and small delivery vehicles. Electric buses, coaches, and light-commercial vehicles are eligible for substantial incentives in China (Cui et al., 2017). The Government of India is making available USD 67 million for electric bus, taxi, and automobile procurement. Up to USD 150,000 per bus is available, and nearly 400 electric buses are expected to be procured across 11 cities as a result of the incentives (UITP, 2018). The rationale behind purchasing incentives is the same regardless of ownership model (privately-owned, public fleet, private fleet) or vehicle type (car, delivery vehicle, bus). In theory, incentive programs could extend eligibility to include all ownership and vehicle types.

Many jurisdictions impose one or more taxes on vehicle purchases, and exempting EVs from value-added or duty taxes is another strategy to lower the cost differential with combustion alternatives and encourage their use. EVs in India, for example, typically face the lowest VAT tax rate (e.g., 5% in Delhi compared to 12.5% for conventional vehicles) and are exempt from state road taxes in many regions (Rokadiya & Bandivadekar, 2016). Figure 1-3 shows the impact of import duty and VAT on the final prices of the all-electric Nissan Leaf compared to a similar gasoline model in four markets (Grant & Lutsey, upcoming). As shown in the figure, Norway fully exempts EVs from all taxes, and the final purchase price of the Nissan Leaf is near cost-competitive with the internal combustion model as a result. In Brazil, EVs are exempt from the import duty tax, but not the 25% VAT (yellow bar). Exempting, or significantly reducing, EVs from these taxes lowers the upfront cost differential between electric and similar internal combustion models, encouraging their adoption. To further lower the upfront cost differential between electric and combustion models, Brazil could consider exempting EVs from national and local VAT (an incentive valued at approximately USD 7,500 for the Nissan Leaf). This example is specific to light-duty vehicles, but the policies apply to all vehicle modes, such as light commercial vehicles and buses. Although not shown in Figure 1-3, some countries have additional taxes and tax exemptions for EVs which can further tip the value proposition in favor of electric models, such as registration or annual circulation taxes (Yang et al., 2016).

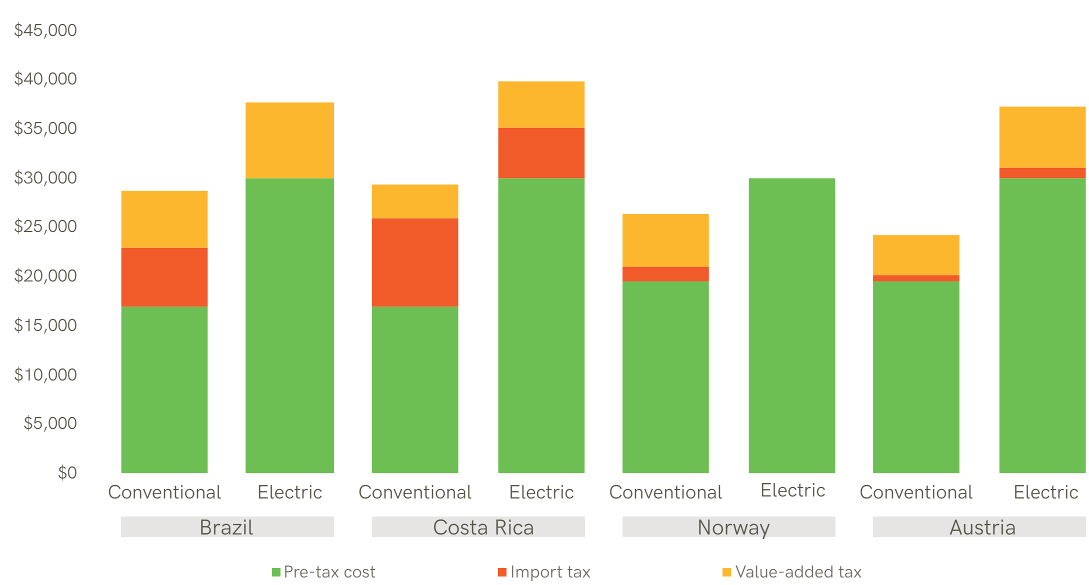

Figure 1-3 | **Final price of a Nissan Leaf compared to a conventional Nissan vehicle after the application of import duty and VAT**[4]

[4] The most representative comparison gasoline model was selected based on availability in the four markets: the Nissan Sentra in Brazil and Costa Rica, and the Nissan Pulsar in Norway and Austria.

EXEMPTIONS FROM ANNUAL FEES

Recurring fiscal incentives for EVs promote their use beyond the initial sale or lease and are available in many markets. Germany and the Netherlands, for example, exempt EVs from annual circulation taxes (Yang et al., 2016). In the United States, 18 states exempt EVs from license and registration fees or emissions inspections tests (Slowik & Lutsey, 2017). Other regions that exempt EVs from annual fees or taxes include China, France, Japan, Sweden, and the United Kingdom (Yang et al., 2016), as well as Telangana and Maharashtra in India. The monetary value of annual exemptions typically is relatively modest compared to the value of purchase incentives, and such recurring incentives are perceived by consumer as less valuable than those available at the point of sale (Yang et al., 2016). However, there are some exemptions: electric public buses in Shanghai received a 165,000 CNY (about USD 26,000) operation subsidy each year from 2013-2015 (Hall et al., 2017b).

PREFERENTIAL ACCESS

Several government programs grant EVs preferential access, providing additional benefits to EV drivers. These typically include free or preferred parking, and access to bus lanes, toll lanes, or high-occupancy vehicle lanes. Such incentives are typically implemented at the provincial or local level and are relatively common and effective measures to raise awareness of electric mobility and promote its adoption.

Germany, for example, allows municipalities to grant special privileges to EV models meeting certain criteria, and Stuttgart has declared EVs eligible for free parking on public lots (Tietge et al., 2016). In the U.S., 10 major metropolitan areas had some form of parking incentive in place during 2016, including free parking at eligible metered locations and select garage parking lots (Slowik & Lutsey, 2017). In Telangana, India, EVs are exempt from toll and parking fees for 7 years after their purchase. In Amsterdam, EVs obtain free public spots and priority permits. Cities with similar parking perks include Copenhagen, Oslo, San Jose, Shanghai, Shenzhen, and Utrecht (Hall et al., 2017a).

Other examples of local parking support include policies that directly provide new designated parking for EVs or policies that increase their number over time. For example, New York City's 2014 policy requires that 25% of new off-street parking be EV-ready. In London, 20% of new parking spaces must have an EV charge point. These types of policies typically mean that future parking facilities are equipped with the proper wiring and panel capacity to handle EV charging. As a co-benefit to promoting EVs, such forward-thinking policies are likely to provide additional financial benefits by avoiding timely and costly retrofits (CARB, 2015). Cities with similar actions include San Francisco, Los Angeles, Shenzhen, Hangzhou, Beijing, Shanghai, and Qingdao (Hall et al., 2017a).

Several local and provincial governments in the U.S. allow single-occupant EVs to use high-occupancy vehicle (HOV) lanes, a perk cited by many EV buyers as a primary motivator in their purchasing decision (Tal & Nicholas, 2014). Previous research estimates the value of HOV access is about USD 2,000 to USD 3,350 over a 6-year period (Slowik & Lutsey, 2017). Several areas provide special road or lane access, such as San Francisco, Los Angeles, San Jose, Oslo, Shenzhen, Bergen, Beijing, Shanghai, Tianjin, Hangzhou, and Taiyuan (Hall et al., 2017a).

While incentives related to preferential access are generally implemented at the provincial or local level, Norway has nationwide incentives including free access to toll roads, reduced ferry rates, access to bus lanes, and free public parking (Tietge et al., 2016), which are key motivating factors for EV drivers (Haugneland & Kvisle, 2013). The reduced ferry rates are gradually being phased out due to high volumes of electric cars. These incentives are a significant perk, estimated to be worth approximately 16,000 kroner (approximately USD 2,500) per year for an EV owner (Assum, Kolbenstvedt, & Figenbaum, 2014).

Preferential access policies are carefully tailored to fit local contexts. For example, the rugged geography of Norway increases the value of exempting EVs from tunnel and ferry tolls (a policy that has since been scaled back due to the volume of electric cars on the roads). In Amsterdam, EV drivers have priority for parking permits, while the waiting list for other vehicles can last years. The congestion in major cities in California makes access to high-occupancy vehicle lanes on freeways a valuable perk (Hall et al., 2017a).

DISCOUNTED OR FREE CHARGING

Lower TCO, including lower maintenance and fueling costs, is a key driver of EV sales, and ensuring that driving on electricity is cheaper than driving on gasoline is crucial to promote broader adoption of EVs (Slowik & Nicholas, 2017). Thus, allowing and encouraging electricity providers to set preferential lower electricity rates for home, workplace, and public EV charging can be an important approach.

Research has shown that restructuring electricity prices can influence consumer charging behavior and reduce EV fueling costs. Time-of-use rates, which offer lower electricity prices during off-peak hours, have already been successfully implemented in many jurisdictions, including California, New York, and Maryland, in the U.S., and Germany, United Kingdom, and Japan (Hall & Lutsey, 2017b). By linking vehicle charging to off-peak, time-of-use rates tend to have advantages for both power utilities and consumers (Hall & Lutsey, 2017b; Ryan & Lavin, 2015). Customers can realize significant savings from time-of-use rates: estimates from across the United States range from USD 200 to USD 450 in annual savings (Salisbury & Toor, 2015). In general, areas with relatively low electricity prices and relatively high conventional fuel prices tend to provide additional financial motivations for the purchase and use of EVs.

Other programs globally are working to ensure that driving on electricity is cheaper than driving on gasoline. Denmark provides tax refunds on electricity used to charge EVs. Norway exempts electricity from fuel taxes and offers free electricity for normal charging (3.6kW). Companies including Nissan, BMW, and Tesla offer fast charging for free of charge for some time after initial vehicle purchase. Although these incentives are industry programs, any entity could subsidize an allotment of charging through an account credit or an offer of free charging for some time (Slowik & Nicholas, 2017). These programs would ideally link vehicle charging to off-peak hours, thereby providing benefits to drivers and power utilities alike.

FINANCING PROGRAMS

Vehicle purchase incentives, as discussed above, are helping to overcome the purchase cost differential between EVs and their combustion counterparts and are available for multiple vehicle types in many markets. Financing schemes may also be necessary to enable the large-scale adoption of electric buses due to their higher initial investment compared to passenger cars. Electric bus financing programs allow transit agencies or other bus operators to purchase vehicles that are outside of their immediate financial reach. Also, federal financing programs provide more attractive conditions for hybrid and electric buses. Hybrid and electric bus purchases are eligible for lower interest rates (1-4.6%) and longer loan terms (12 years) compared to diesel buses (7.3%, 6-9 years, respectively) (BNDES, 2018). Financing schemes for electric buses can help tip the TCO value proposition in favor of the electric model. A 2017 ICCT analysis addresses the opportunities for facilitating, and the barriers to financing, the transition to soot-free (including electric) urban buses in 20 cities worldwide (Miller et al., 2017).

Financing programs have applicability beyond buses. A USD 2 million program in California offers attractive financing for businesses to provide EV charging stations at their locations (California Pollution Control Financing Authority, 2018). In the United Kingdom, the Scottish Government offers loans of up to £35,000 for EV purchases with 6-year repayment terms (Energy Savings Trust, 2018).

Table 1-3 summarizes the international consumer incentives for EVs.

Table 1-3 | **International consumer incentives for EVs**

Incentive	Description	Rationale	Typical stakeholder	Implications for EV adoption
Subsidies for vehicle purchase	A fiscal subsidy for the purchase or lease of an EV	Lower the cost differential between electric and internal combustion models	National or provincial government	Strong relationship with high EV adoption
Tax exemption for vehicle purchase	A tax exemption for the purchase or lease of an EV	Lower the cost differential between electric and internal combustion models	National or provincial government	Strong relationship with high EV adoption
Exemption from annual fees	Recurring incentives available after initial purchase or lease	Lower the operating costs of EVs through annual exemptions	National or provincial government	Modest increase in the financial value proposition
Preferential lane access	Special or free access to toll roads, HOV lanes, bus lanes, ferries	Increase the attractiveness of driving electric, increase public awareness	Provincial or local government	Often a key purchasing motivation for customers in some markets
Preferential parking access	Special or free access to parking	Increase the attractiveness of driving electric	Provincial or local government	Additional perks to driving electric
Discounted/ free charging	Cheap or free electricity for EV charging	Incentivize driving electric by lowering the operating costs	National or provincial government, utility, or private sector	Low operating costs to attract prospective buyers
Financing programs	Provide upfront capital to businesses or consumers to support EV purchase	Lower capital for vehicle purchase and allow smaller payments over time, ideally with modest interest rates	National or provincial government, private sector	Lower upfront cost barrier. Important for high capital vehicles such as e-buses

CHARGING INFRASTRUCTURE

Availability of electric vehicle supply equipment (EVSE) supports the adoption of EVs by helping to overcome range and inconvenience barriers. A greater network of charging infrastructure can increase driver confidence in the vehicle's range and expand the vehicle's operating functionality (NRC, 2015). Multiple studies highlight the importance of home and workplace charging for private car owners (Bailey et al., 2015; Lin & Greene, 2011; Lutsey et al., 2016; NRC, 2015; Zhou et al., 2017). Similarly, the availability of public charging infrastructure is widely considered a key factor to encourage EV uptake (Hall & Lutsey, 2017a; Lutsey et al., 2015, 2016; Slowik & Lutsey, 2017; Tietge et al., 2016). A 2017 ICCT study outlines emerging global best practices for EVSE (Hall & Lutsey, 2017a).

Figure 1-4 shows the amount of public charging infrastructure (Level 2 and DC fast) and EV sales in major metropolitan areas globally. Public charge points per million population are shown on the x-axis; cumulative EV sales per million population are shown on the y-axis. The bubble size reflects the number of EVs sold in 2016. The data are colored according to country, and several markets with high EV sales are labeled.

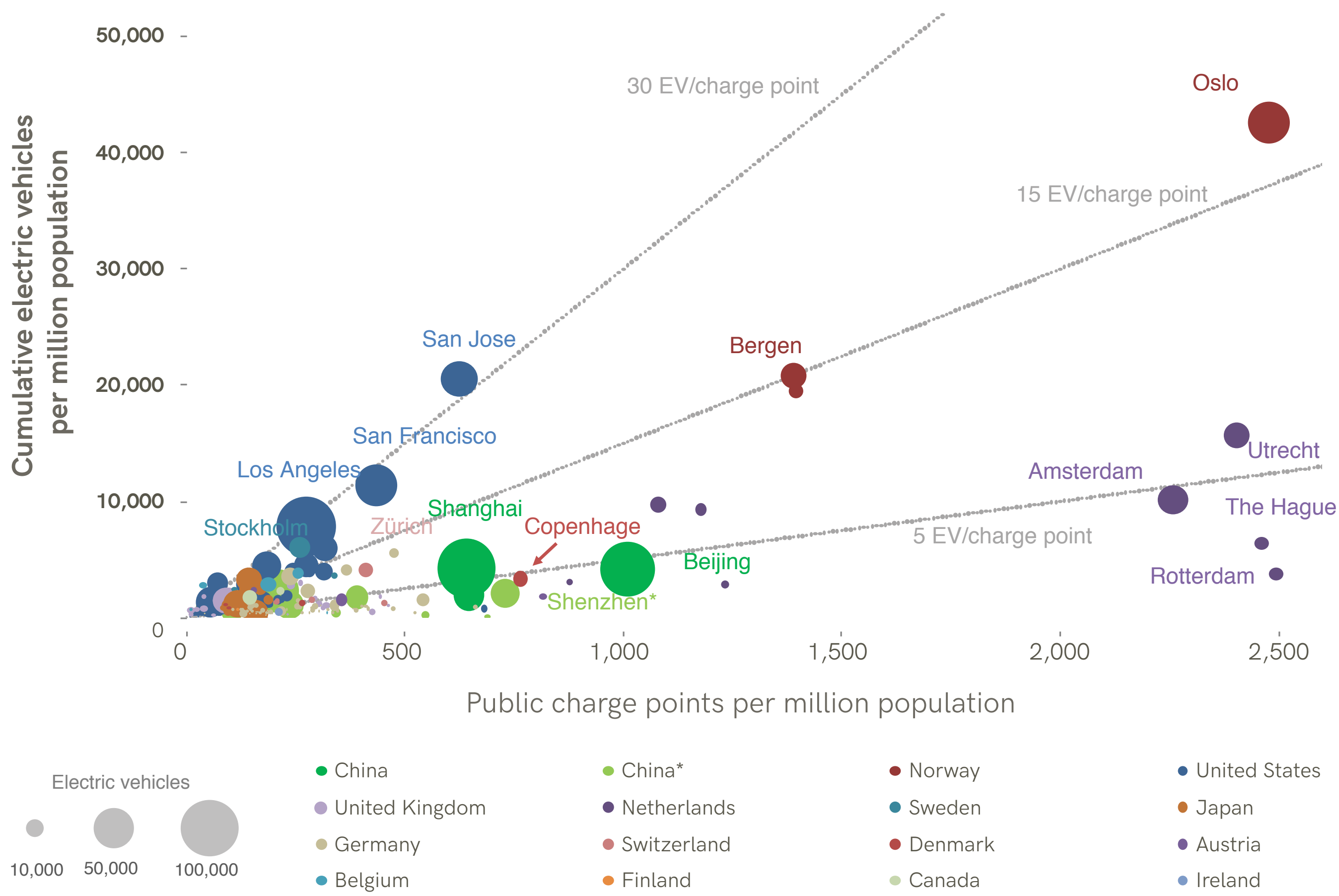

Figure 1-4 | **Public charging infrastructure and EV registrations per million population by metropolitan area**[5]

[5] Based on emerging best practices for electric vehicle charging infrastructure (Hall & Lutsey, 2017a).

The figure shows that many of the markets with high cumulative EV sales, high annual 2016 sales, or high sales shares, tend to have relatively high public charging infrastructure deployment. The data cluster at the lower left reflects the early state of EV market development at present. In most markets with below 5,000 EVs per million population and fewer than 400 charge points per million population, fewer than 1% of new vehicle sales are electric (Hall & Lutsey, 2017a). Many local factors, such as the prevalence of residences with private garages (and thus access to home charging), have implications on the need for public chargers. There is a relatively low number of private garages in the Netherlands, for example, and these cities have a high ratio of public chargers to EVs.

Actions by governments, utilities, and industry are leading to a substantial increase in the size of the global charging infrastructure network. The various charging infrastructure programs assessed below include standard protocols for EVSE, EVSE incentives, direct deployment, and EV-ready building codes.

STANDARD PROTOCOLS FOR EVSE

Early deployment of EVSE was developed relatively fragmented, with multiple stakeholders deploying various types without a shared long-term vision. Today, standards for physical plugs have largely been accepted, however the back-end communications, payment, and power supply standards have been less standardized (Hall & Lutsey, 2017a). This requires drivers to have multiple membership accounts and access cards to use the infrastructure, reducing charging feasibility and practicality.

To overcome this challenge, the Netherlands regulates every public charging station in the country, requiring all network operators to adopt common standards. Such standardization ensures that EV drivers can charge at any station with a single identification or payment method, and that all stations can communicate equally with EVs. Driving and charging EVs in the Netherlands is much easier, affordable, and practical as a result. Other stakeholders are similarly working to promote EVSE interoperability through standardization, such as Germany, California, Washington State, Massachusetts, and multiple industry groups including BMW, Bosch, Siemens, EnBW, Nissan, ChargePoint, and EVgo (Hall & Lutsey, 2017a). Such efforts are important to support the long-term growth of EVSE networks and to overcome barriers related to EV charging practicality.

Adopting standard protocols can also provide benefits in the electric bus sector. The standardization and interoperability of charging technologies across industry can help alleviate the risks of "lock-in" to purchasing buses from one particular manufacturer (Miller et al., 2017). Industry groups including the European Automobile Manufacturers Association offer recommendations in support of charging infrastructure interoperability across manufacturers.

EVSE INCENTIVES OR FUNDING

Many governments and electric power utilities help to enable electric mobility by providing financial incentives for charging infrastructure to residences and/or commercial businesses, or by funding its deployment. Recent ICCT studies outline several global national and provincial level charging infrastructure programs, their budgets, and the varying support mechanisms (Hall & Lutsey, 2017a; Hall et al., 2017b; Slowik & Lutsey, 2017).

France and Denmark provide tax incentives for the installation of charging stations, and some local governments, such as Paris and Copenhagen, offer additional grants. The Netherlands provided €16 million in 2011 to support early infrastructure deployment, and its Green Deal initiative aims to increase public charging by making available €5.7 million EVSE installations. State governments in India, including Karnataka, Telangana, and Maharashtra, typically provide a 25% capital subsidy for a limited number of commercial public charging stations. Additional subsidies for private and semi-private charge points are available in municipalities such as Amsterdam and Utrecht. Other governments, such as California, Canada, Germany, Shenzhen, and the United Kingdom, offer some sort of private and/or public incentive for charging infrastructure.

Electric power utility Austin Energy, in the U.S., provides incentives for both residential and commercial EVSE, valued at up to USD 1,500 for privately owned Level 2 residential stations, USD 4,000 for semi-public stations, and up to USD 10,000 for publicly-available DC fast stations (Slowik & Nicholas, 2017). A handful of additional U.S. utilities provide financial incentives for the purchase and installation of EVSE (Slowik & Lutsey, 2017).

Several governments have dedicated public funding to support growth of the public charging network. Federal funding in the U.S. has supported the rollout of over 20,000 charge points at 8,000 stations (Lutsey, 2015). Japan has a similar program with funding dedicated through 2018. China's central government subsidizes construction of charging stations and supports their rollout with written guidelines. The United Kingdom and Norwegian governments are financing public stations every 30-50 kilometers on major roads.

DIRECT DEPLOYMENT

Utilities are increasingly directly deploying publicly available charging infrastructure. In California, the state Public Utilities Commission has approved rate-based light-duty EVSE rollout plans that will deploy over 12,500 charging stations across major service territories (CPUC, 2016; Edison International, 2016; SDG&E, 2016). Several additional utility transportation electrification applications are under consideration in California that would allocate significant funds to charging infrastructure, with about USD 780 million to medium and heavy-duty vehicles including e-buses, USD 230 for residential EVSE, USD 13 million for off-road infrastructure, and USD 30 million for public fast chargers (CARB, 2018b).

As part of the Volkswagen settlement in the U.S., the company will invest USD 2 billion over 10 years that largely go to EVSE deployment. The first 2.5-year cycle will bring several thousand charge points at 900 sites across the U.S., including local community charging and fast charging corridors capable of providing 350kW (several times faster than many existing DC fast chargers, which typically provide 50kW-100kW). Similar efforts are underway in Japan, led by Toyota, Nissan, Honda, and Mitsubishi (Toyota, 2014), and in Europe, where four industry groups (BMW, Daimler, Ford, and Volkswagen) are collaborating to construct 400 high-power-charging stations (350kW) across 18 European countries by 2020 (Ionity, 2018).

EV-READY BUILDING CODES

Governments at various levels have implemented regulations to promote charging infrastructure, especially by mandating EV-ready infrastructure in new buildings. Such initiatives increase the feasibility of EV adoption while helping to avoid costly retrofits, estimated at up to USD 6,975 per charging station in California (CARB, 2015). California's Green Building Standards Code, for example, requires in 2015 that 3% of all parking spaces in commercial buildings include dedicated panel and circuit capacity, thus being EV-ready (CARB, 2015). The regulation requires an increasing percentage of parking spaces to be EV-ready and higher-powered capacity over time. Some municipal governments in California have adopted ordinances that go above and beyond the state requirements. San Francisco and surrounding cities require at least 10% of parking in multifamily dwellings and new commercial buildings to be EV-ready, and Los Angeles requires all single-family homes have a dedicated 240-V outlet and circuit capacity for a Level 2 charger with additional requirements for other building types (Hall & Lutsey, 2017a; Slowik & Lutsey, 2017).

Outside of the U.S., the European Union has drafted regulations that would require EVSE in new or refurbished homes beginning in 2019. Similar policies are being considered in Germany. At the local level, London requires an EV charge point at 20% of parking spaces in new developments, as well as make-ready infrastructure for an additional 20% (Greater London Authority, 2016). Vancouver has implemented similar requirements. These types of policies help ensure sufficient future infrastructure to support electric mobility.

EV IMPACTS ON BATTERY DISPOSAL AND ELECTRICITY GRIDS

While transportation electrification is commonly seen as a key measure to reduce pollutant and GHG emissions, there may be other electric vehicle issues to address, such as the eventual disposal of electric vehicle battery packs and electric vehicle's negative impacts on the electric power grid. Yet the early EV industry is rapidly developing solutions to these challenges, with battery second life applications and advanced recycling processes (Hall & Lutsey, 2018). Furthermore, research and demonstration projects are showing how electric vehicles can not only mitigate the potential impacts on the power grid, but even provide substantial economic and social benefits to utilities and ratepayers alike (E3, 2016).

Many stakeholders within the electric power industry have been hesitant to proactively support electromobility, primarily due to the potential technical and logistical challenges to serving a large number of EVs simultaneously. In particular, the simultaneous uncontrolled charging of a very large number of electric vehicles poses risks to grid overloads and increasing peak load factors when electricity is typically most expensive and carbon-intensive. One study in California estimates that the uncontrolled charging of electric vehicles during peak hours could require grid upgrade expenses of around $150 per vehicle (Berkheimer et al., 2014). However, with proper planning, these costs could be substantially reduced, and utilities can benefit greatly from increased transportation electrification in future years (E3, 2015).

Electricity sales in the U.S. and Europe are projected to plateau or decline in coming decades due to energy efficiency programs and distributed power generation. Electrification of transport represents a source of new electricity demand that is likely to increase for decades, a major opportunity for load growth and utility business. This load growth boosts utility sales and provides benefits to all ratepayers by reducing the average cost of service (E3, 2016). Electric vehicles can also provide significant grid stability benefits due to their flexibility and energy storage capabilities. Controlled charging programs that encourage charging off-peak (or discourage charging on-peak) can help minimize the risks to grid overloading.

Several utility-controlled charging programs have been effective at shifting electric vehicle charging, thereby providing grid benefits. In addition, several trials are underway to study and commercialize more technologically advanced electric vehicle charging applications, such as vehicle demand response, vehicle-to-grid power supply, and utilizing batteries for second-life applications beyond the vehicle lifetime (Hall & Lutsey, 2017b). These future capabilities hold promise to provide even greater grid flexibilities and benefits. Recent ICCT research on global utility best practices regarding electric vehicles summarizes the core opportunities and challenges and highlights several emerging exemplary utility programs that are promoting electromobility (Hall & Lutsey, 2017b). These questions certainly warrant further investigation, including a better understanding of the end-of-use pathways of today's internal combustion vehicle and their components including lead-acid batteries, as well as the upstream externalities of well-to-wheel petroleum supply and its global price volatility.

Table 1-4 summarizes international charging infrastructure programs for EVs.

Table 1-4 | **International charging infrastructure programs for EVs**

Charging infrastructure	Description	Rationale	Typical stakeholder	Implications for EV adoption
Standard protocols for EVSE	Protocols that require industry to adopt a set of defined EVSE requirements	Ensure EVSE-EV communication and allow EV drivers to charge anywhere with a single payment method	International, national, or provincial government	Increase the feasibility and practicality of driving electric
EVSE incentives or funding	Financial incentives for the purchase of EVSE	Lower the cost of installing EVSE and expand the charging network	National or provincial government, utility	Charging infrastructure is considered a key factor to encourage EV adoption
Direct deployment	Installation of charging infrastructure	Increase vehicle functional electric range, reduce range anxiety, and raise public awareness	National government, utility, or industry	Charging infrastructure is considered a key factor to encourage EV adoption
EV-ready building codes	Electrical panel and conduit capacity requirements for buildings	Increase the availability of EVSE in the long term and avoid retrofit costs	Provincial or local government	Ensuring sufficient infrastructure to support EV adoption in the long term

PLANNING, POLICY, AND OTHER PROMOTIONS

Governments have implemented a variety of additional policy and planning actions beyond the clean vehicle and fuel regulations, consumer incentives, and charging infrastructure actions described above. These policies and activities generally include electric-mobility strategies, outreach and awareness programs, demonstration projects, procurement targets, and fleet initiatives. This section evaluates how various planning, policy, and other promotion actions are supporting EV adoption around the world.

PROCUREMENT TARGETS

Defining EV deployment targets is often a key first step to establish a common long-term electric-drive vision. Such goals send clear signals about the pace of development and amount of resources that will be needed. Establishing targets can lead to the creation of a taskforce or working group to chart out a path for achieving goals, including the development of an official electric mobility strategy and key market support policies and actions.

Many national, provincial, and local governments have set short- and long-term EV procurement targets that cover multiple vehicles. Based on several national and provincial government announcements through 2015 (California, China, Denmark, France, Germany, India, Japan, Netherlands, Norway, Ontario, South Korea, Spain, Sweden, United Kingdom, and United States), global cumulative sales goals sum to at least 15 million light-duty EVs by 2020, and more than 25 million in the 2025-2030 timeframe (Lutsey, 2015). A collaboration of 14 governments that make up the International Zero-Emission Vehicle Alliance publicly announced their commitment to strive for 100% of passenger vehicle sales to be zero-emission no later than 2050 (ZEV Alliance, 2018). Energy service company EESL of the Government of India issued a competitive bid for the procurement of 10,000 EVs for its fleet (EESL, 2017), and the company is expected to float tenders for additional procurement to eventually replace the central government fleet of up to 500,000 vehicles. Government targets are often updated to reflect market development and progress on climate and clear air goals. In 2018, for example, California called for a new target of 5 million ZEVs by 2030, building on the previous goal of 1.5 million by 2025 (State of California, 2018).

Local governments have also set strong EV procurement targets. Oslo, Los Angeles, Stockholm, Beijing, London, and San Francisco have announced ambitions to become EV capitals or leaders (Hall et al., 2017a). Amsterdam and Oslo have announced targets for 100% zero-emissions transport by 2025 and 2030, respectively. London and Shenzhen are striving for 70,000 and 120,000 EVs by 2020, respectively. Los Angeles is aiming for 25% of the vehicle stock to be electric by 2035, and New York City is reaching for a 20% EV sales share by 2025.

Procurement targets can focus on specific vehicle types and services. Los Angeles has a goal for half of the municipal vehicle fleet to be electric by 2017, and similar programs are underway in Oslo, Amsterdam, San Jose, New York, Shenzhen, and elsewhere. Beijing is replacing its entire taxi fleet with EVs, and similar programs are underway in London, Amsterdam, Hangzhou, Tianjin, and elsewhere. Shenzhen converted its entire public bus fleet of 16,000 buses to electric, an initiative that began in 2009 driven by urban pollution and supported with strong government financial incentives, infrastructure, and industrial policy. Several actions helped to accelerate the e-bus transition in Shenzhen, including both national and local subsidies, leasing options, optimized charging to realize low-fuel prices, and lifetime battery warranties from bus manufacturers (Xue & Zhou, 2018). Los Angeles, the second largest bus fleet in the U.S., committed to a fully electric bus fleet (about 2,200 buses) by 2030, and similar initiatives are underway in Paris, Amsterdam, London, Shanghai, Beijing, Tianjin, Hangzhou, Qingdao, and Taiyuan. In Chile, transit agency Transantiago will procure at least 90 electric BYD buses across six private operators through the government tender process (Global Mass Transit, 2017). These procurement targets and more are summarized in Hall et al. (2017a).

ELECTRIC MOBILITY STRATEGIES

Many metropolitan areas have some form of EV strategy crafted to local or regional contexts. These are commonly called "action" or "readiness" plans and can cover many vehicle modes and services: private cars, taxis, public fleets, commercial vehicles, or buses. Such strategies play an important role by creating a forum and network of local and state governments, power utilities, charging providers, auto dealerships, and other organizations to discuss common issues about electric mobility. These action plans help to identify and shape local actions to overcome EV adoption barriers (e.g., cost, convenience, infrastructure, awareness) and to prepare local infrastructure and utilities to support the recharging of many EVs on local roads. Electric mobility plans typically lead to the implementation of additional local policies and support actions to promote electric mobility. Many urban areas with high EV adoption have published one or more plans (Hall et al., 2017b). One particularly comprehensive plan in the U.S. is the City of Portland's Electric Vehicle Strategy (2017).

Several active governments at the provincial and national levels have also implemented readiness plans. China's Made in China 2025 plan includes EV adoption goals, direction for R&D, infrastructure deployment, financial incentives, and outlines a vision for several regional "pilot" cities (MIIT, 2015). Telangana, India, issued a draft EV policy in 2017 which outlines several key objectives, strategies, and policy measures, such as mandates, manufacturing incentives, vehicle and infrastructure financial incentives, local perks, and more (Telangana Electric Vehicle Policy, 2017). The United Kingdom government launched a 500-million-pound plan that includes R&D, consumer incentives, charging infrastructure, and local support actions (OLEV, 2014). In the U.S., eight states are collaborating on a Multi-State ZEV action plan to prioritize and enact complementary actions to support EV deployment and use (NESCAUM, 2014). California has implemented one of the most comprehensive EV support plans (Governor's Interagency Working Group on Zero-Emission Vehicles, 2016).

OUTREACH AND AWARENESS PROGRAMS

Consumer awareness and education is key to widespread EV adoption; however, despite actions to date, the public lacks basic knowledge related to EVs (Kurani et al., 2016; NRC, 2015; Singer, 2015). Numerous actions can be taken to increase familiarity with EVs and understanding of their key features. Recent ICCT research summarizes these actions and their implementation around the world (Jin & Slowik, 2017).

Outreach events are an effective way to raise awareness and increase familiarity. These include EV showcases, ribbon-cutting ceremonies for public charging stations, charging station giveaways, and ride-and-drive events. National Drive Electric Week is one of the largest outreach programs in North America, with 235 events in 212 cities. Many local governments, industry groups, and organizations participate in or support the events, which include proclamations by local officials, ribbon-cuttings for public charging stations, charging station giveaways, ride-and-drives, and more (Plug In America, 2016). Bus manufacturer Blue Bird has also hosted ride-and-drives across multiple U.S. cities in its all-electric school buses.

The United Kingdom launched a multi-million-pound collaborative outreach campaign with industry in 2013 to increase public awareness of the benefits, cost savings, and capabilities of EVs. The Go Ultra Low campaign brings together the Government's Office for Low Emission Vehicles, the Society of Motor Manufacturers and Traders, and car manufacturers on a brand-agnostic campaign designed to encourage more drivers to go electric. The campaign includes national press, radio and digital advertising, consumer firsthand events, community-focused programs, fleet-focused press, and social media outreach (Jin & Slowik, 2017).

Although it is difficult to quantify the effectiveness of outreach events in spurring EV uptake, there is apparent evidence of success. Firsthand experiences with the technology tends to increase the likelihood of future adoption (Slowik & Nicholas, 2017). For example, 9% of survey respondents purchased or leased an EV within 3 months of attending a ride-and-drive event in California (PEVC, 2017). Many others reported visiting dealerships, talking to EV owners, researching EVs online, or sharing their experiences with friends, family and co-workers, enhancing the greater community network effect and increasing overall awareness. Nearly all major EV markets in North America, Europe, and Asia have launched awareness, education, and outreach programs (Jin & Slowik, 2017).

DEMONSTRATION PROJECTS

Executing highly visible technology demonstration projects are a great way to test new technologies while raising public awareness and exposure and promoting market adoption. Most major vehicle markets support some sort of EV demonstration project.

China declared Shanghai an International EV Demonstration City, and an important element of the designation was the creation of the EV Demonstration Zone. The zone is a hub for electromobility, offering a suite of services including sales, public test drives, business mode innovation (carsharing, rentals), data collection, service and maintenance, infrastructure support, and marketing. More than 50 industry organizations have become partners to the Zone, which also has nearly 10,000 members (Jin & Slowik, 2017). The growth of the Shanghai EV Demonstration Zone has occurred with the growth of the EV market. Shanghai is a top market both nationally and globally for EV sales (Hall et al., 2017a, 2017b). The many elements within the EV Demonstration Zone help to ensure that the public were well informed about the EV technology and support its adoption (Jin & Slowik, 2017).

Similar efforts launched in Germany in 2011, when the federal government implemented multiple demonstration projects through the Electromobility Model Regions and Showcase Regions for Electric Mobility programs. The projects support R&D of more than 100 projects and more than 300 activities to overcome key technological and social barriers and enable everyday electric mobility (Jin & Slowik, 2017). The showcase regions include testing of electric buses in urban environments to evaluate their real-world applicability, emission reductions, cost-benefits, and public acceptance.

California has a unique program dedicated to accelerating advanced technology vehicles not yet commercialized. The Advanced Technology Demonstration Projects program makes available millions of dollars each year to fund numerous projects carried out by eligible local air districts, public agencies, and non-profit organizations (CARB, 2018c). Relevant recent projects include both on-road and off-road demonstrations, including electric school buses, multi-class heavy-duty zero-emission trucks, zero-emission drayage trucks, and electric yard trucks. Through outreach, education, and positive experience, the program increases public and industry acceptance of EV technology.

The Zero Emission Urban Bus System (ZeEUS) project in the European Union provides a platform for cities pursuing bus electrification to share their demonstration project experiences. The European-Commission-funded project established an observatory of electric bus system activities including monitoring of demonstration projects, development of an annual evaluation report, and an internet platform. Ten cities across nine European countries are designated zero-emission urban bus core demonstration cities, including Barcelona, Bonn, Cagliari, Eindhoven, London, Münster, Paris, Plzen, Stockholm, and Warsaw (ZeEUS, 2014). The platform provides transit agencies with knowledge and materials to support broader adoption of zero-emission buses (ZeEUS, 2017).

FLEET INITIATIVES

Integrating EVs into fleets directly increases their use while helping to overcome barriers to their wider adoption by expanding overall visibility and exposure (Jin & Slowik, 2017; NRC, 2015). Integrating EVs within a fleet can also lower total costs, reduce emissions, and enhance awareness, public relations, and brand image. One study found that the TCO of battery electric delivery vehicles is cheaper than diesel vehicles in several countries when considering tax policies (Kleiner et al., 2015). There are many fleet-based light-duty EV carsharing, ride-hailing, and taxi initiatives, as well as several electric urban delivery vehicle initiatives. Some examples are summarized in Table 1-5.

Table 1-5 | **Electric carshare, ride-hail, taxi, urban delivery, and bus fleet initiatives**

Fleet type	Key organization	Location	Time frame	Description	Source
Electric carsharing	Car2go	Amsterdam, Madrid, Stuttgart	2012-present	EV carsharing service using over 13,500 Smart ForTwo vehicles in multiple European cities	Daimler, 2018
Electric carsharing	BlueIndy	Indianapolis, U.S.	2015-present	EV carsharing service using 500 Bollore Bluecar vehicles	BlueIndy, 2018
Electric ride-hailing	Uber, Energy Savings Trust	London	2016-2017	Uber program to pilot EVs on its platform over a 6-month period with 50 partner drivers and evaluate the challenges and opportunities for scale-up	Lewis-Jones & Roberts, 2017
Electric taxis	BBF Schipholtaxi, BIOS-groep, Nissan	Amsterdam	2014-present	Fully electric taxi fleet serving Schiphol airport with 167 Tesla Model S and 170 Nissan Leaf vehicles	Joseph, 2014; Nissan, 2015
Electric taxis	Beijing government and local taxi industry	Beijing	2017-present	Goal to replace about 70,000 combustion taxis with EVs to improve local air quality	King, 2017
Urban logistics EVs	European Green Vehicles Initiative	Eight cities in Europe	2013	Testing of 80 freight EVs for daily delivery operations in 8 European cities, finding this is a technically reliable alternative	EGVI, 2013
Urban distribution EVs	CW, boco, UPS, Smith Electric Vehicles, EFA-S	North Rhine-Westphalia, Germany	2011-2015	A two-year demonstration project that took data of 107,402 km driven by battery powered electric trucks for urban distribution	Moultak et al., 2017
Electric delivery trucks	Renault Trucks	Paris	2015	Testing of the all-electric D-range on delivery rounds of over 200 km with multiple battery recharge times during a 24-h operating cycle	Moultak et al., 2017
Electric parcel and letter delivery trucks	German Post AG, StreetScooter GmbH, Langmatz GmbH, BMUB	Bonn	2012-2016	CO_2 GoGreen's effort to improve the vehicle technology, infrastructure technology, energy supply, and process design for using EVs in parcel and letter delivery	Moultak et al., 2017
Electric delivery trucks	SJVUAPCD, Motiv Power Systems, AmeriPride Services, CALSTART	Central Valley, California	2016	Deployment of 20 electric walk-in-vans and their charging infrastructure for deliveries. Funded through USD 7.1M grant from CARB, USD 5.8M from partners	Moultak et al., 2017
Electric parcel delivery trucks	SJVAPCD, USPS, EDI, CALSTART, SunEdison	Stockton & Fresno, California	2016	Deployment of 15 all electric USPS "step vans" and charging infrastructure to form the basis of a USPS Advanced Vehicle Cluster. The project received USD 4.5M in California funds	Moultak et al., 2017
Electric delivery vehicles	Gnewt Cargo	Southwark, UK	2017	Lease of 33 EVs for last-mile logistics	Moultak et al., 2017
Electric delivery trucks	Nordresa, Purolator	Québec	2017	The trials show electric trucks saving an average of 0.60 CAN per kilometer resulting in profitable operation within 2 years	Moultak et al., 2017
Electric delivery trucks	UPS	Amsterdam	2013	UPS deployed 6 electric parcel delivery trucks in Amsterdam	Moultak et al., 2017

Fleet type	Key organization	Location	Time frame	Description	Source
Light-duty cars and utility trucks	Pacific Gas & Electric	Northern California	2015-2020	Utility to invest 33% of annual fleet budget (~USD 100 million over 5 years) in electric light-duty vehicles and work trucks. Electrification lowers operating costs, extends vehicle life, reduces emissions, and allows the utility to deliver electricity during emergencies	PG&E, 2015
Electric buses	King County Metro	Washington	2017-2033	Agency e-bus feasibility study that recommends all future purchases be zero-emission. Current e-bus technology was found capable of meeting 70% of service needs, growing to 100% with continued technological advancements. Procuring 1,400 e-buses can reduce emissions by 80% and advance social equity, while increasing costs by 6%	King County Metro, 2017
Electric buses	City of Shenzhen	Shenzhen	2009-2018	Conversion of Shenzhen' entire public fleet of 16,000 buses to electric, an initiative that began in 2009 driven by urban pollution and supported with strong government financial incentives, infrastructure, and industrial policy	Bullard, 2017
Electric buses	Government of India	11 cities, including Delhi	2017	Issue of USD 67 million for procurement of nearly approximately 400 electric buses across 11 cities. Delhi has initiated a separate plan to procure 700 electric buses using its state budget	UITP, 2018

Vehicles in urban delivery operation that offer a shorter radius from their base location, lower daily distances, less volume and mass constraints for cargo, and recharge in just one or two locations are suited for plug-in electric trucks. Many such vehicles are in local city government operations, short-distance urban cargo delivery, electric power utility service vehicles, and other applications in every major city. Several major automakers are adapting their electric car technology for light-commercial vans. The Deutsche Post StreetScooter is a recent example of the commercialization of electric truck technology for urban settings (Moultak et al., 2017).

Regional and international initiatives are promoting bus electrification as part of a broader set of transport technology pollution mitigation solutions, such as the C40 Clean Bus Declaration or the Union Internationale des Transports Publics (UITP) ZeEUS project (C40 Cities, 2014; UITP, 2014). The ZeEUS project supports market adoption of urban electric buses through technology demonstration and evaluation, and by providing policymakers with guidelines and tools to support the introduction of electric buses. The ZeEUS annual 2017 report provides an update on the global electric bus market observed dynamics and trends and discusses several initiatives in this area (ZeEUS, 2017).

LOW-EMISSION VEHICLE ZONES

Low-emission vehicle zones can also promote EVs to some degree. London implemented a low emission zone in 2008, requiring light commercial vehicles, buses, and other heavy-duty vehicles that operate in the city center to emit fewer pollutants or pay a daily charge. There is therefore a direct incentive for operators to adopt less polluting vehicle technologies, which include EVs. London has announced a second more stringent "ultra-low emission zone" will come into force in 2019. The policy will cover additional vehicle types, including passenger cars, requiring them to meet strict emission standards or pay a daily fine.

In the Netherlands, the City of Utrecht implemented a low-emission zone that applies to passenger and urban delivery vehicles. Paris, Oslo, and Beijing, among others, have announced restrictions on the most polluting vehicles in order to improve air quality. Increasing the emissions requirements of those zones and expanding their breadth to cover all vehicle types will progressively promote more advanced vehicle technologies including EVs. These restrictions make EVs a very attractive long-term option for residents and businesses alike.

Table 1-6 summarizes international planning, policy, and other EV promotions.

Table 1-6 | **International planning, policy, and other EV promotions**

Action	Description	Rationale	Typical stakeholder	Implications for EV adoption
Procurement targets	A goal or objective outlining EV adoption ambitions	Send clear signals about pace of development and resources needed to achieve EV, air quality, and climate change targets	National, provincial, or local government	Often a first step towards charting out an EV strategy and policy implementation
Electric-mobility strategy	An action or readiness plan amongst a network of stakeholders	Identify and shape actions to overcome key EV barriers and prepare for their adoption	National, provincial, or local government	Often a first step towards launching key EV support programs and initiatives
Outreach and awareness	Programs that educate the public about the benefits of EVs and raise awareness	Overcome a key barrier by raising public familiarity and understanding	Provincial or local government	Greater knowledge and firsthand experience to increase the likelihood of EV adoption
Demonstration projects	Test and publicize emerging technologies	Prove market readiness of new technologies, raise public and industry awareness and acceptance	National or provincial government	A first step towards commercialization., for increasing exposure can enhance the likelihood of adoption
Fleet initiatives	Programs that work to integrate EVs into fleets.	Lower total costs, reduce emissions, and enhance awareness, public relations, and brand image	National, provincial, or local government, utility, or industry	Direct increase in EV usage, visibility, and exposure
Low-emission vehicle zones	An area where vehicle access is restricted or discouraged based on tailpipe emissions	Restrict high-polluting vehicles from the urban core to improve air quality	Local government	Direct economic incentive to adopt advanced technology, including EVs

SUMMARY OF INTERNATIONAL EVALUATION

Several actions are supporting EV adoption by increasing their affordability, practicality, and awareness. Many actions by many policy and industry stakeholders are key to reducing consumer barriers related to EV uptake with supporting policy, incentives, infrastructure, and consumer awareness. National and provincial governments develop policy, implement incentive programs, and support with infrastructure rollout, whereas cities focus more on local policies and nonfinancial consumer programs, and utilities and industry groups are increasingly engaged in infrastructure deployment and consumer education.

A previous ICCT analysis summarized key literature findings related to EV policy effectiveness (Lutsey, 2015). The studies generally indicate that many actions by national, provincial, and local governments, as well as other stakeholders (vehicle manufacturers, charging providers, utilities, and other organizations) will be needed through 2025 to support the transition to electric.

Table 1-7 summarizes the EV promotion actions considered in this evaluation and their implementation in major markets. The left-hand side of the table shows the various regions' light-duty EV sales and sales share. As shown, many of the key support actions are in place in many of these markets, which account for about 91% of cumulative global EV sales. Most of the areas with high EV adoption are those where many actions are in place including regulations, multiple incentives and infrastructure programs, and are actively involved in planning, policy, and other promotions.

Table 1-7 | **Government EV promotion actions in selected areas**

Area	Approximate 2017 sales and sales shares		Clean vehicle and fuel regulations			Consumer incentives							Charging infrastructure				Planning, policy, and other promotions					
			Clean vehicle mandates	Fuel efficiency standards	Clean fuel standards that credit electricity	Subsidies for vehicle purchase	Tax exemptions for vehicle purchase	Exemption from annual fees	Preferential lane access	Preferential parking access	Discounted or free charging	Financing programs	Standard protocols for EVSE	EVSE incentives or funding	Direct deployment	EV-ready building codes	Procurement targets	Electric-mobility strategy	Outreach and awareness	Demonstration projects	Fleet initiatives	Low-emission vehicle zones
Canada	19,000	0.9%	/	X	/	/					/			X	/	/	X	/	/	/	/	
China	600,200	2.1%	X	X		X	X	X		/	/			X	/	/	X	X	/	X	X	/
France	36,900	1.8%		X		X	X	X		/				X	X	X	X	/	/	/	X	/
Germany	53,500	1.6%		X		X	X	X	/	/	X	/	X	X	X		X	X	X	X	X	
Japan	55,900	1.1%		X		X	X	X			X			X	X	/	X	X	/	/	X	
Netherlands	9,200	2.2%		X		/	X	X	X	/	X		X	X	X		X	X	X	X	X	/
Norway	62,200	39.2%		X			X	X	X	/	X			X	X	/	X	X	X	/	X	/
UK	48,400	1.9%		X		X	X	X		/	/	X		X	X	/	X	X	X	X	X	/
U.S. (excl. California)	96,000	0.7%	/	X		X	/	/	/	/	/		/	X	/	/	X	X	/	/	/	
California	96,500	4.9%	X	X	X	X			X	/	X	X	X	X	X	/	X	X	X	X	X	

x denotes national program and / means smaller local or regional program.
Data retrieved from Hall and Lutsey (2017a, 2017b), Hall et al. (2017a, 2017b), Jin and Slowik (2017), Lutsey (2015), Slowik and Lutsey (2017), Tietge et al. (2016), Yang et al. (2016). 2017 sales and sales shares based on CNCDA (2018) and EAFO (2018).

Although the data in the table is specific to light-duty vehicles, the policies are applicable to all vehicle types, such as fleet vehicles, urban delivery vehicles, buses, or other heavy-duty vehicles. Many of the policies in place are supporting the electrification of passenger cars, commercial vehicles, and buses; however, depending on the government decision, some policies only target a specific vehicle type. Programs that currently limit vehicle eligibility could be modified or extended to include the broader vehicle market.

The table shows how overall, the areas with the greatest number of policies and support actions tend to see the most market response. This finding is consistent with previous analyses that identify a comprehensive package of policy and promotion actions by provincial, local, utility, and other private stakeholders as key for developing the EV market (Lutsey et al., 2015, 2016; Slowik & Lutsey, 2017). The actions underway in major EV markets help to provide a template for actions that could be more widely deployed by national, provincial, and local governments. There are many smaller local or regional programs supporting electric mobility in urban environments around the world (indicated by /). Table 1-8 highlights prominent local-level actions discussed in this international evaluation and provides examples of their successful implementation.

Table 1-8 | **Innovative EV support actions and example cities**

Policy or program	Model city	Details	Cities with similar action
City fleet goal	Los Angeles	Half of city fleet electric as of 2017	Oslo, Amsterdam, San Jose, New York, San Diego, Shenzhen, Tianjin
Taxi electrification	Beijing	Replacing all 69,000 city taxis with EVs through government subsidies	Taiyuan, London, Amsterdam, Hangzhou, Tianjin, Shenzhen, Qingdao, Pune, Hyderabad, Chennai, Bengaluru, Mexico City

Policy or program	Model city	Details	Cities with similar action
Electric car sharing program	Paris	4,000 cars and 6,000 charge points	Shanghai, Los Angeles, Amsterdam, London, Hangzhou, Beijing, Shenzhen, Tianjin, Qingdao, Taiyuan
Electric car rental program	Bengaluru	Plan to deploy 1,000 EVs for enterprise service by Mahindra & Baghirathi Group brand "rydS"	Shenzhen, San Francisco
Public bus electrification	Shenzhen	All buses zero-emission by October 2017	Bengaluru, Hyderabad, Delhi, Santiago, Los Angeles, London, Shanghai, Beijing, Tianjin, Hangzhou, Qingdao, Taiyuan
Free public charging	Oslo	Free charging with renewable energy at all Level 2 charge points	Stockholm, Bergen
EV-friendly building and parking codes	London	1 EV charge point in every 5 new parking spaces	San Francisco, Los Angeles, New York, Shenzhen, Hangzhou, Beijing, Shanghai, Qingdao
Special road or lane access	San Francisco	Use of carpool lanes and payment of reduced bridge tolls by EVs	Los Angeles, San Jose, Oslo, Shenzhen, Bergen, San Diego, Beijing, Shanghai, Tianjin, Hangzhou, Taiyuan
Designated EV zones	Hyderabad	Permission of EVs only to circulate in high-traffic areas, Heritage zones, special economic zones, and EV zones	London, Utrecht
Vehicle registration benefits	Shanghai	EVs bypass expensive license plate auction system	Beijing, Shenzhen, Tianjin, Hangzhou
Parking benefits	Amsterdam	Free public parking spots and priority for permits for EVs	Shanghai, Utrecht, Oslo, San Jose, Shenzhen, Taiyuan
Local purchase incentives	Qingdao	Local subsidies of USD 5,000-USD 9,000 per EV	Beijing, Shanghai, The Hague, Hangzhou, Tianjin, Shenzhen, Taiyuan
Exemption from driving restrictions	Santiago	Exemption from regulations which restrict vehicles from driving two days each week for EVs	Beijing

Based on Hall et al. (2017a).

Local support policies in leading cities are carefully tailored to fit local contexts. For example, the rugged geography of Norway increases the value of exempting EVs from tunnel and ferry tolls (a policy that has been scaled back due to the volume of electric cars on the roads). Major cities in China, suffering from heavy congestion and pollution, have implemented strict vehicle registration quotas; exempting EVs from this quota makes them very attractive to residents and sends a strong signal that electric mobility is the future. Additionally, some of these cities in China allow electric cars to drive even on days when internal combustion engine vehicles are banned. In California, the congestion in major cities makes access to HOV lanes on freeways a valuable perk. In Amsterdam, EV drivers have priority for parking permits, while the waiting list for other vehicles can last years (Hall et al., 2017a).

Around 99% of the global electric bus fleet on roads today is in China. Driven by the urgent need for clean air, the central and local governments have supported the electric bus transition with a strong policy vision and procurement targets, significant financial purchase incentives, charging infrastructure support, and friendly industrial policy for local bus manufacturing. Between 2009 and 2017, Shenzhen converted its entire fleet of 16,000 buses to electric, a success story that is ripe for further evaluation and understanding of the key lessons learned and best practice implementation strategies that can be shared more broadly.

Regions across North America, Europe, China, and elsewhere are implementing incentives, developing long-term regulatory policy, and deploying charging infrastructure to support the EV market. Markets in Europe and China are experimenting with similar and even bolder policies that explicitly promote EVs.

Governments around the world stand to gain from learning from each other's policy and market experiences. The collective adoption of similar actions to help overcome barriers and develop EV markets will help all regions around the world achieve air pollution, climate, and fuel saving benefits. The more markets embrace the leading EV policies, the faster the transition to a global EV fleet will occur.

2

MOTIVATION FACTORS FOR VEHICLE ELECTRIFICATION IN BRAZIL

The analysis of motivation factors applied to the Brazilian context is relevant for the design of electromobility public policies. Around the world, governments are implementing a robust portfolio of policies and activities to promote electric vehicles and help strengthen energy and environmental security, reduce oil consumption, climate emissions and local air pollution, and establish a position of industrial leadership in advanced technologies. Many urban areas are struggling against severe pollution and public health threats associated with pollution from motor vehicles. Electrification of transportation is commonly seen as a centerpiece to improve urban pollution. Aside from the social and environmental benefits of electromobility, many governments seek economic, industrial, and employment benefits as a result of the research, development and manufacture of electric vehicles and the respective infrastructure.

This chapter presents a brief overview of the still incipient EV market in Brazil before addressing motivation factors in this context. These include fuel consumption and CO_2 emissions, energy security and trade balances, energy efficiency, air quality and noise, and the electricity generation mix.

BRAZILIAN ELECTRIC VEHICLE MARKET OVERVIEW

The market for plug-in and battery electric vehicles in Brazil is nearly non-existent, with less than 200 cumulative new EVs between 2010 and 2017 (Anfavea, 2018). When we compare this figure to the total sales of electric vehicles in the world, surpassing 1.2 million in 2017, we can see the delay in the advancement of these technologies in Brazil. In contrast to the small EV fleet, which is all imported, the national market is primarily served by industries installed in Brazil, with imported vehicles accounting for 11% of vehicle licensing in 2017.

Despite the economic crisis since 2014 (Figure 2-1), Brazil is still among the world's foremost vehicle markets, in addition to representing more than half of sales in Latin America (Posada & Façanha, 2015). In 2017, 2.24 million vehicles were licensed in the country, and the estimated fleet reached 43.6 million units (Anfavea, 2018). According to projections, there will be 54.7 million light-duty vehicles in Brazil in 2026 (MME, 2017). In other words, it is estimated that this fleet will increase 25.4% in the next nine years in Brazil, and thus provide a major market opportunity for EV growth.

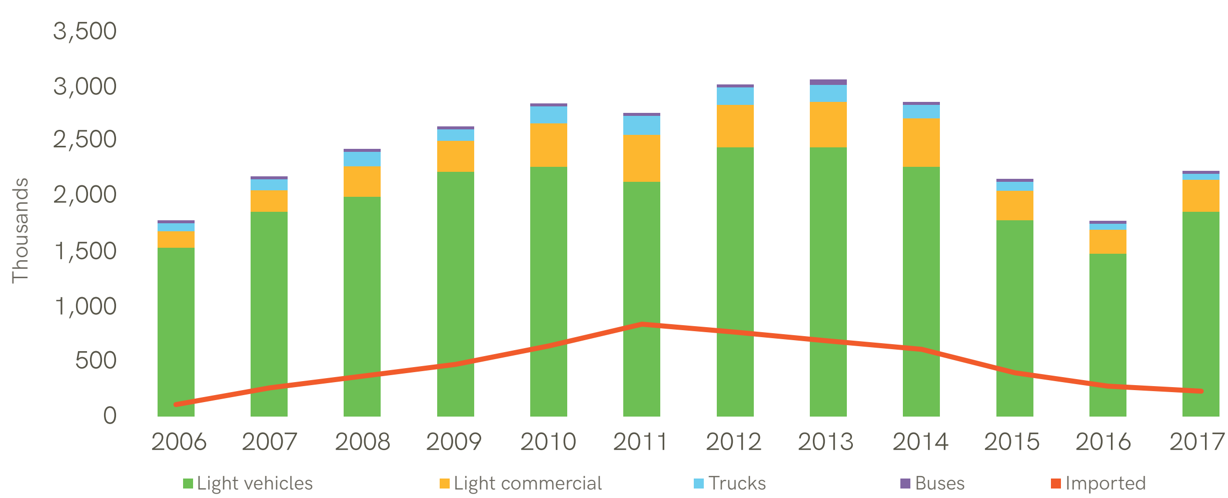

Figure 2-1 | **Licensing of new vehicles in Brazil**

Although there are experiments including electric buses, these are also incipient compared to the estimated fleet of 382,260 buses that circulate throughout Brazil (Sindipeças, 2018). These small-scale experiments include the electric buses being tested in some cities, produced by Eletra and, more recently, by China-based BYD. But these are *ad hoc* experiences, limited especially by cost and infrastructure barriers. The technology is also undergoing an accelerated evolutionary process, especially the batteries.

Experiences to stimulate EVs in Brazil have proved insufficient when compared to the best international practices (Consoni, 2017; Marx, 2014). *Ad hoc* actions can be identified, usually focused on demonstration, studies and research, or reduction of taxes, with few effective results. This overview has shown some signs of change, and electromobility is now on the governmental agenda. But, in spite of limited initiatives to expand the fleet of EVs, no actions or coordinated policies have been implemented in Brazil.

FUEL CONSUMPTION AND CO_2 EMISSIONS IN THE TRANSPORTATION SECTOR

Fuel consumption and emissions of pollutants and GHG by motor vehicles are significant. Figure 2-2 shows historical (EPE, 2017b) and future (MME, 2017) fuel consumption for road transportation in Brazil by fuel type.

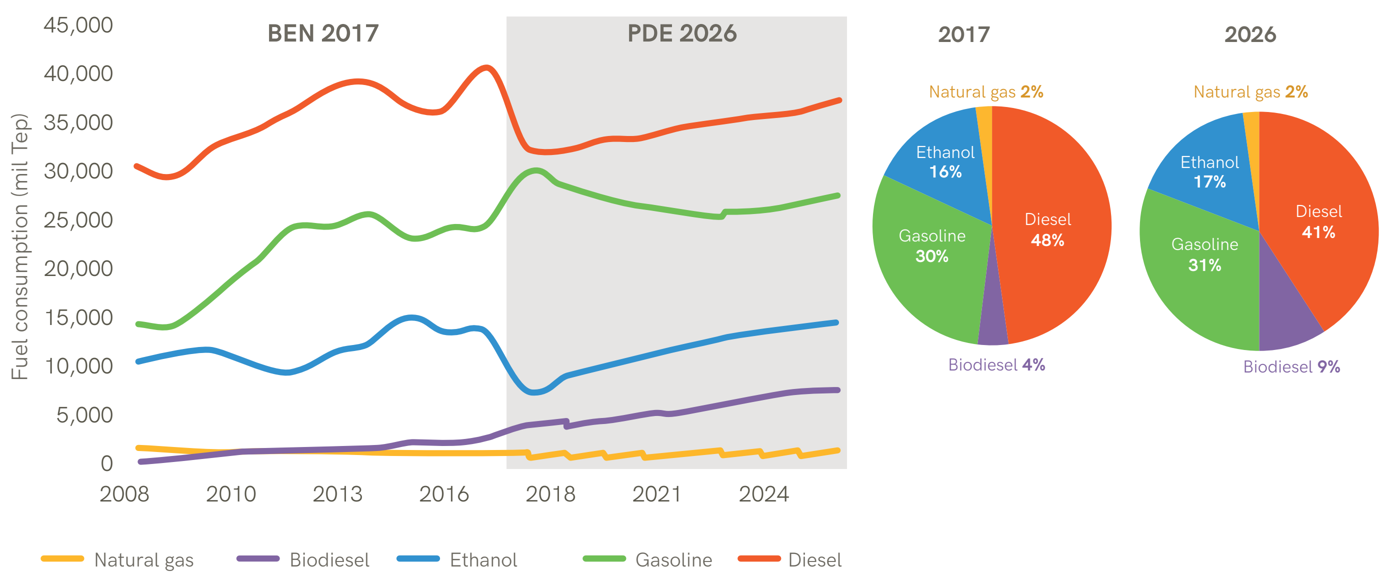

Figure 2-2 | **Fuel consumption for road transportation by fuel type in Brazil**

Although the renewable fuel market is relatively developed in Brazil when compared to other countries, projections of the Ten-Year Energy Plan (PDE 2026) indicate that the largest share of road fuel consumption will continue to be of fossil origin. In 2017, 80% of the fuel consumed in road transportation – in tonnes of oil equivalent (toe) – was non-renewable and will remain the predominant fuel type through 2026. A reduction in fossil sources is forecast in the period, which will account for 71% of total road fuel consumption in 2026 (Figure 2-3). The estimated 9% increase in the participation of renewable fuels in 2026 in relation to the total road fuel consumption is mainly driven by greater use of ethanol over gasoline in flex-fuel vehicles. In the reference scenario of PDE 2026, an increase in energy efficiency was also assumed, but there is no forecast of EVs aside from a small portion of imported gasoline hybrid vehicles. In absolute terms, a decrease of fossil fuel of only 3.8% (in toe) is projected in the next decade.

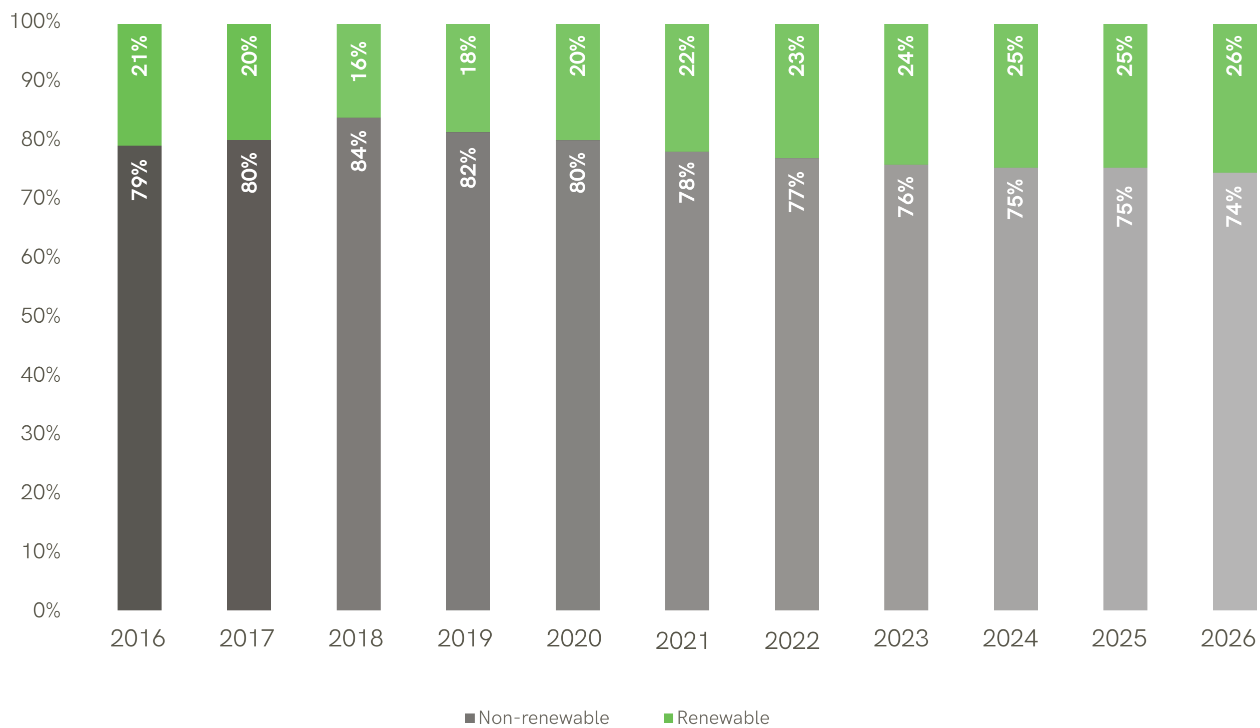

Figure 2-3 | **Participation of fossil fuels and renewable fuels in road transportation**[6]

As a consequence of high dependence on fossil fuels, the transportation sector in 2016 contributed with 51% of total GHG emissions from fuel combustion (Figure 2-4). Nearly all transportation emissions were generated by road transportation, reflecting its dominance in Brazil and the high carbon intensity. Heavy-duty vehicles accounted for most of the emissions (66.2%) of the road sector.

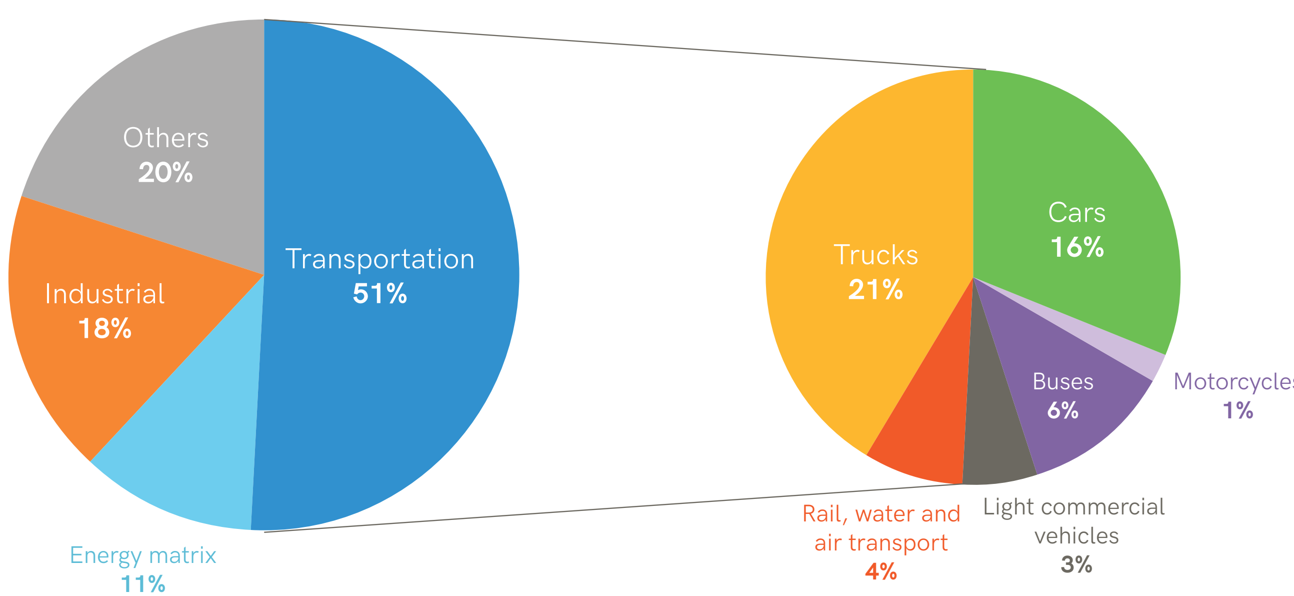

Figure 2-4 | **GHG emissions from fuel combustion in 2016 in Brazil (OC, 2017)**

[6] Prepared by the authors based on the complete historical series of the National Energy Balance (BEN) and the Ten-Year Energy Plan (PDE) 2026 (MME, 2017).

The Brazilian government committed to contribute to the mitigation of GHGs by adhering to the Paris Agreement, signed at the 21st Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015. In its Nationally Determined Contribution (NDC), Brazil proposed a reduction in its GHG emissions of 37% below 2005 levels by 2025. Furthermore, it submitted a subsequent indicative contribution of 43% below 2005 emission levels, to be reached by 2030. It should be noted that the NDC does not associate goals with specific sectors, so the nation can allocate its efforts to the most cost-effective measures. There is, however, a reference regarding emission estimates in 2025 and 2030 in the document Fundamentals for the Development of Brazil's Intended Nationally Determined Contribution (INDC) in the context of the Paris Agreement, segmented by sector or economic activity (MMA, 2016).[7]

Among the guidelines that supported the NDC in terms of transportation is the increase in the share of sustainable bioenergy, contributing to the decarbonization of the sector:

> *(...) increase the share of sustainable bioenergy in the Brazilian energy matrix to approximately 18% by 2030, expanding the consumption of biofuels, and enhancing the supply of ethanol, also by enlarging the share of advanced biofuels (second generation) and the share of biodiesel in the diesel mix.*

The NDC also includes recommendations for promoting energy efficiency measures, improvements in transportation infrastructure, and public transportation in urban areas. Although electromobility is not mentioned explicitly in the guidelines of this document, it can be considered as part of the energy efficiency measures.

In 2016, Brazil had already met the NDC's guidelines on the share of biofuels, representing 18.4% of the energy matrix (Figure 2-5).[8] According to the 2026 National Energy Plan (MME, 2017), biofuels will account for 21.4% in 2026, considering ethanol and biodiesel.[9] The relative growth in biofuel consumption is mainly due to the increased use of ethanol in flex-fuel vehicles, partially replacing gasoline consumption. An increase in the share of biodiesel is also projected, to meet legal requirements of the B100 blend in diesel.[10]

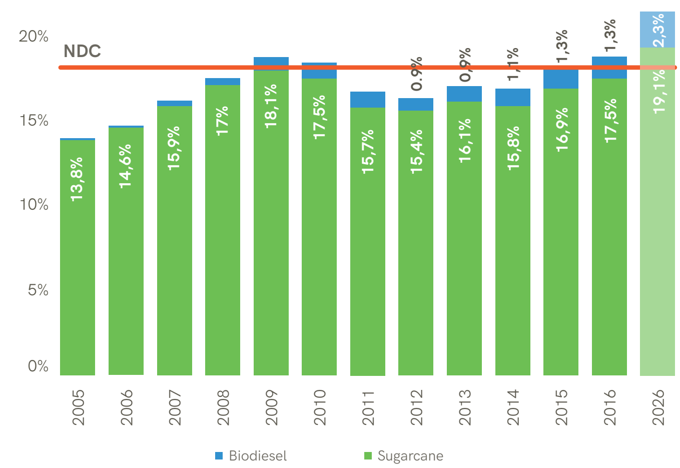

Figure 2-5 | **Share of sugarcane and biodiesel products in the Brazilian energy matrix**

Although consistent with the guidelines established in the Brazilian NDC, the result of these estimates, with decarbonization due to the greater use of biofuels in transportation, would lead to a 43% increase in GHG emissions in the transportation sector in 2026 from 2005 levels (Figure 2-6). This is because projections of increasing fuel demand more than offset the increase in biofuel shares, resulting – in absolute terms – in an increase in fossil fuel consumption. In a scenario of higher economic growth, emissions would increase by 53.6% in 2026 compared to 2005, according to PDE 2026.

[7] For the energy sector, which includes transportation, emissions were projected to increase by 80% and 113% in 2020 and 2025, respectively, compared to 2005.

[8] Sugarcane products and biodiesel were considered as sustainable bioenergy.

[9] Although the Ten-Year Energy Plans have a guiding character, they are an important planning instrument for various sectors.

[10] Law 13.623/2016 established the timeline for increasing biodiesel content in diesel: 8% by March 2017; 9% by March 2018; and 10% by March 2019. It also provided for the possibility of increasing these percentages by up to 15% after conducting trials on engines. In 2017, CNPE Resolution 23 of November 9, anticipated the mandatory percentage of 10% to March 2018.

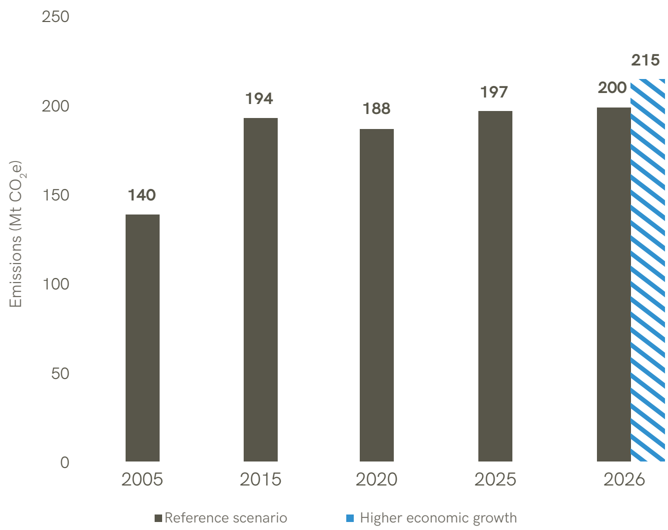

Figure 2-6 | **Estimates of GHG emissions for the transportation sector based on the premises adopted in PDE 2026**

ENERGY SECURITY AND TRADE BALANCES

Another factor that has been considered a motivator for electromobility is energy security. Energy security is understood as the provision of sufficient energy resources to meet the current and future needs of citizens, including the services available to them and the industrial processes. This definition involves guaranteeing the supply of domestic energy sources to avoid external dependence. In this respect, there are two types of fuels in the supply of energy for transportation: fossil and renewable fuels.

Regarding fossil fuels, Brazil has a positive trade balance for oil, having exported 38% of its production in 2017 (Figure 2-7). Estimated oil production will more than double in 2026, mainly due to the contribution of the pre-salt layer. According to PDE 2026, the percentage of exported oil will increase to 65% of the total amount produced in 2026, making it a major world player. However, there are limitations in oil processing capacity, and Brazil also imports some diesel and gasoline, with a projected deficit by 2026 (Figure 2-8).

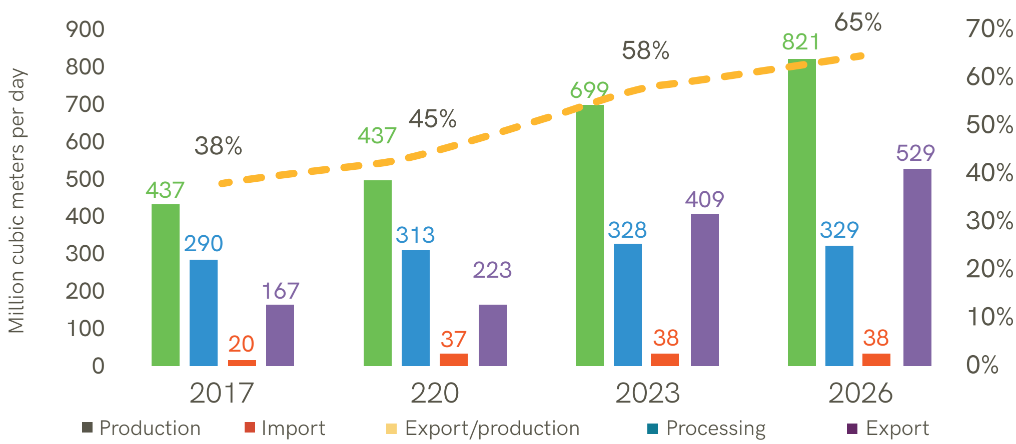

Figure 2-7 | **Brazilian oil balance projections in 2017-2026 (PDE 2026)**

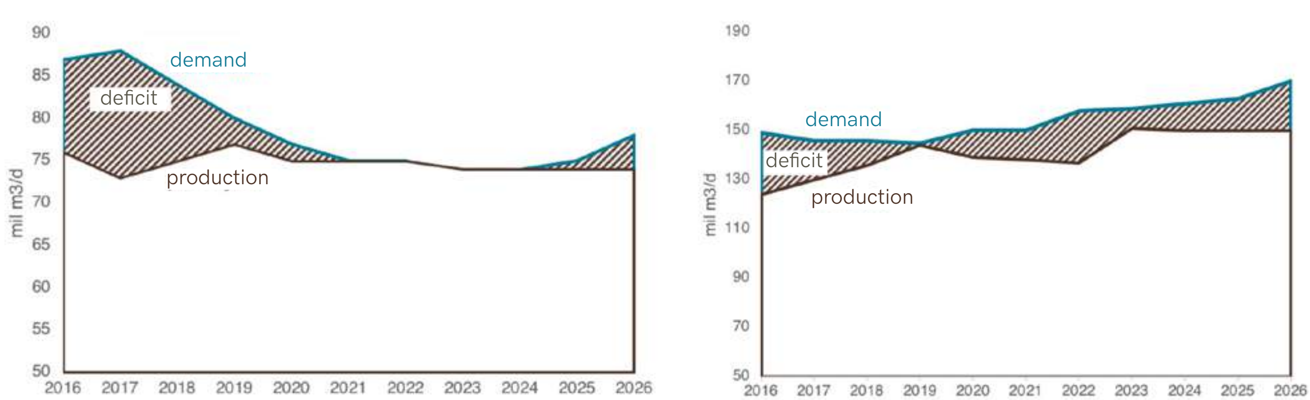

Figure 2-8 | **Brazilian balance of gasoline A (left) and diesel A (right)**

In the case of renewables (biodiesel and ethanol), PDE 2026 also projects expanded supply and demand. Uncertainties for renewable projections are greater because they are more highly subject to climate conditions and the price of agricultural commodities, such as soy and sugarcane.

PDE 2026 projects an 18.5% deficit for biodiesel in 2026, considering the projections of demand based on approved biodiesel blends. This deficit can be even greater assuming an increase in the percentage of biodiesel blends, a higher demand because of macroeconomic factors, or reduced supply due to capacity constraints.[11]

In the case of ethanol, in order to meet NDC's targets, a 57% increase in demand is expected in the 2016-2026 decade. Assumptions are made to increase supply based on investments and productivity gains for the sugar/ethanol industry, corn ethanol production, and advancement of second-generation ethanol. In 2017, ethanol was imported to meet domestic demand.[12]

The import of anhydrous ethanol will not be significant in 2018-2026, according to PND 2026. However, if planned investments are not made, there will be an 11% reduction in the estimated supply. In this case, in order to meet the demand for light-duty vehicles, the alternatives include greater use of gasoline or ethanol imports. The former alternative would negatively impact GHG targets, while the latter could also negatively impact GHG targets if imported ethanol is from corn because of its higher carbon content compared to sugarcane ethanol.

ENERGY EFFICIENCY

EVs have energy efficiency three to five times higher than internal combustion vehicles (Lutsey, 2012). In other words, regardless of the source of energy used, vehicle electrification alone represents gains in energy consumption. However, consideration should be given to the energy sources being replaced from the viewpoint of GHG emissions. This gain in efficiency, and its respective effects on GHG emissions, are potentiated in situations where the energy generation matrix is predominantly renewable, as in Brazil (more than 80%), and where the replaced fuel is of fossil origin, such as diesel and gasoline.

AIR QUALITY AND NOISE

In addition to the positive effects related to climate and energy security, another factor that induces electromobility is urban air quality and its impact on public health. Emissions of pollutants from fuel burning in internal combustion engines are generally the main reason for the poor air quality in big cities (Cetesb, 2018). The main pollutants resulting from the internal combustion of fuels in vehicles are:

- **Particulate matter (PM):** in a simplified way, this can be defined as solid or liquid particles suspended in the air, the aerodynamic diameter of which varies from 2.5 µm, fine fraction ($PM_{2.5}$), to 10 µm (PM_{10}). Depending on the particle size distribution, they may be trapped in the upper respiratory tract or penetrate deeper into the pulmonary alveoli. Harmful health effects include respiratory cancer, arteriosclerosis, lung inflammation, worsening of asthma symptoms and cardiovascular diseases, damage to the immune system, increased hospital admissions, and possibly death;

- **Hydrocarbons (HC):** resulting from incomplete combustion and evaporation of fuels and other volatile organic components, they play a role in the reactions of tropospheric ozone formation and have the potential to cause the greenhouse effect (methane).

- **Nitrogen oxides (NOx):** they are nitrogen oxide (NO) and nitrogen dioxide (NO_2), which play a major role in the formation of tropospheric ozone. At high concentrations, they lead to serious respiratory problems.

- **Carbon monoxide (CO):** formed in the fuel burning process, this odorless, colorless gas has a high affinity for hemoglobin in the blood, replacing oxygen and reducing the supply of oxygen to the brain, the heart, and the rest of the body during the breathing process. At low concentrations, it causes fatigue and chest pain, and at high concentrations can lead to asphyxia and death.

- **Sulfur dioxide (SO_2)**: emitted by natural sources or by anthropogenic sources, this toxic and colorless gas can react with other compounds in the atmosphere, forming small particulate matter. The anthropogenic emission is caused by the burning of fossil fuels

[11] In PDE 2026, the risk of shortage is considered low, for the biodiesel producing sector has been dynamic and can adapt to the projected demand.

[12] According to the EPE, several factors led to this importation of ethanol, such as the loss of competitiveness of Brazilian ethanol with the end of presumed PIS/Cofins credit starting in January 2017, and the lower domestic prices on the U.S. market with an oversupply of ethanol in that region.

containing sulfur. Among the health effects is the worsening of the symptoms of asthma and the increase of hospitalizations due to respiratory problems.

Some studies have sought to identify the contribution of the main sources of emissions to air quality. Saldiva and André (2009) investigated the contribution of specific sources to PM2.5 emissions in six Brazilian cities: São Paulo, Rio de Janeiro, Curitiba, Belo Horizonte, Recife, and Porto Alegre. The portion attributed to vehicular sources is 40% on average, reaching as high as 55% in the case of Curitiba.

The relative contribution of emission sources varies by pollutant. In the São Paulo Metropolitan Region (RMSP), with a fleet of 11.5 million vehicles in 2016, light- and heavy-duty vehicles are the main sources of ozone precursor pollutants, hydrocarbons, nitrogen oxides, and particulate matter (Figure 2-9).[13] These emissions negatively impact air quality, with a direct effect on public health.

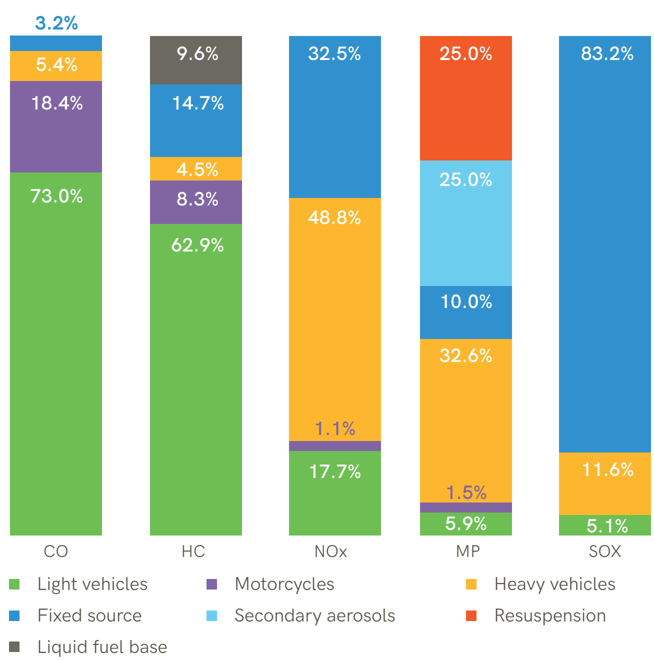

Figure 2-9 | **Relative emissions by type of source in the São Paulo Metropolitan Region (Cetesb, 2018)**

A comparison of air quality in São Paulo in 2015 with the air quality standards recommended by the World Health Organization (WHO) indicates that (Saldiva & Vormitagg, 2017):[14]

- Tropospheric ozone: the WHO standard (100 µg/m^3) was exceeded on 1,034 days. There are stations where the standard was exceeded more than 70 times, and the emergency level (160 µg/m^3) was exceeded 61 times.
- Particulate matter: for inhalable particles (PM10), WHO standards were exceeded at 48 automatic stations (92% of the overall number of stations), totaling 872 days of excess readings at all stations. For inhalable fine particles ($PM_{2.5}$), the annual standard of 10µg/m^3 was exceeded at all automatic stations in Greater São Paulo. The daily pattern was exceeded at several stations; some exceeded the standards nearly 100 times in 2015.

Therefore, data from the RMSP monitoring network indicate that daily and annual patterns have frequently exceeded PM10, $PM_{2.5}$ and ozone pollutants compared to WHO recommendations in Brazil's most populous metropolitan region, where more than 21 million people live. And these pollutants are the most harmful to health, having shown excess levels reaching two-thirds or nearly all of the days in 2015.

This situation doesn't only occur in Brazil's largest metropolitan region. According to WHO data (WHO, 2016a), of the 45 Brazilian cities covered by its Air Pollution Database, in 38, the limits recommended for fine particulate matter ($PM_{2.5}$) are exceeded. Tropospheric ozone (O_3) has also been a problem in major metropolitan areas of Brazil.

Several studies have sought to quantify the health impacts of air pollution, estimating the costs associated with morbidity and mortality, and especially related to motor vehicle emissions (Anenberg et al., 2017; Blumberg et al., 2018; Chambliss et al., 2013; Façanha & Miller, 2016). These studies assess the impact of various policies and

[13] Ozone is a secondary pollutant, i.e., it forms from other air pollutants, such as nitrogen dioxide and volatile organic compounds, in the presence of solar radiation. It is highly oxidizing in the troposphere, and its health effects include the worsening of symptoms of respiratory and cardiovascular diseases.

[14] The air quality standards recommended by the WHO (2006) indicate the health risk threshold based on worldwide efforts and extensive studies, although – according to the organization – there are no safe levels of concentration of pollutants for human health. The recommended standards are stricter than those currently adopted in Brazil, established by Conama Resolution 3/1990. The São Paulo standards are already stricter than Brazilian national standards, but still fall short of those recommended by the WHO.

actions that lead to the reduction of vehicle emissions and point out the gains in terms of early deaths avoided, clearly stating that the benefits often outweigh the costs of introducing these measures when monetarized.[15]

With respect to public transportation in the city of São Paulo, a recent study quantified the health impacts of introducing technological alternatives for the city's bus fleet, considering three scenarios: (i) threshold scenario, or worst case scenario, where the current trend with diesel predominance will be maintained (B7);[16] (ii) scenario with 100% renewable fuels composing the transition to electric buses with hybrids (B100+electric) and biodiesel (B100) and electric; (iii) optimistic scenario, with replacement of the entire fleet by electric buses by 2020 (André et al., 2017).

The result of this study indicated that by 2050, if the current trend of the diesel fleet is maintained, particulate air pollution in the city of São Paulo will be responsible for more than 178,000 early deaths and 189,298 hospitalizations due to aggravated health, which in monetary terms would mean a loss of R$ 54 billion in productivity.[17] In the case of incorporating low emission technologies, as in the 100% renewable scenario, it is estimated that 12,191 premature deaths would be avoided, and in the optimistic scenario, with 100% electric diesel replacement, 12,789 deaths would be avoided. The benefit in productivity from electrification in relation to the threshold scenario considering early deaths avoided is R$ 3.8 billion, accumulated up to the year 2050. Therefore, the health impact of poor air quality is significant, and the gains from adopting cleaner technologies are more than justified.

To improve air quality, it is necessary to have specific actions on vehicles. In the case of internal combustion engines, although control technologies have evolved significantly, the increase in the fleet of vehicles has supplanted those gains which are not sufficient to offset worsening air quality (Cetesb, 2017). Fleet growth, estimated at 25.4% over the next nine years (MME, 2017), will tend to worsen air quality in cities.

EVs emerge as a key solution to serious air quality problems, especially in crowded cities, because their emissions are eliminated at the point of consumption, along with incentives to use collective over individual transportation.[18]

Besides air pollution, vehicles are a source of noise. In large cities, people are exposed to increasing and ongoing noise pollution, affecting quality of life and public health. This is another advantage of EVs: they are extremely quiet. This enables new solutions for facilitating freight transportation, such as nighttime deliveries to ease congestion.

ELECTRICITY GENERATION MIX IN BRAZIL

The advantages of vehicle electrification as a way to replace fossil fuels are amplified when electricity is generated by renewable sources, like in Brazil, where 80.9% of the electricity offered in 2016 was renewable (Figure 2-10). As a result of this matrix, Brazil has one of the lowest CO_2 emission factors per MWh when compared to other countries (Figure 2-11).

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[15] As an example for the Brazilian case, Façanha and Miller (2016) concluded that introducing new limits for heavy-duty vehicles, compatible with Euro VI (Proconve P-8), is highly cost-effective to reduce environmental impacts and health effects caused by heavy-duty diesel vehicles in Brazil. Over a 30-year period starting in 2018, the P-8 regulation would result in health benefits valued at USD 74 billion, at a cost of USD 7 billion, therefore having a benefit-cost ratio of 11:1.

[16] Although the current legislation already requires B10, the study was prior to this requirement, previously expected for 2019.

[17] According to the study, this value is conservative and therefore underestimated.

[18] Emissions would be the result of the power generation process, and not the vehicle's electric motor. Even if there are emissions based on the energy source used for power generation, such as thermoelectric plants, these emissions generally occur farther away from urban centers, and are easier to control with available technologies than mobile sources. The greater energy efficiency of electric motors compared to internal combustion engines reinforces these gains.

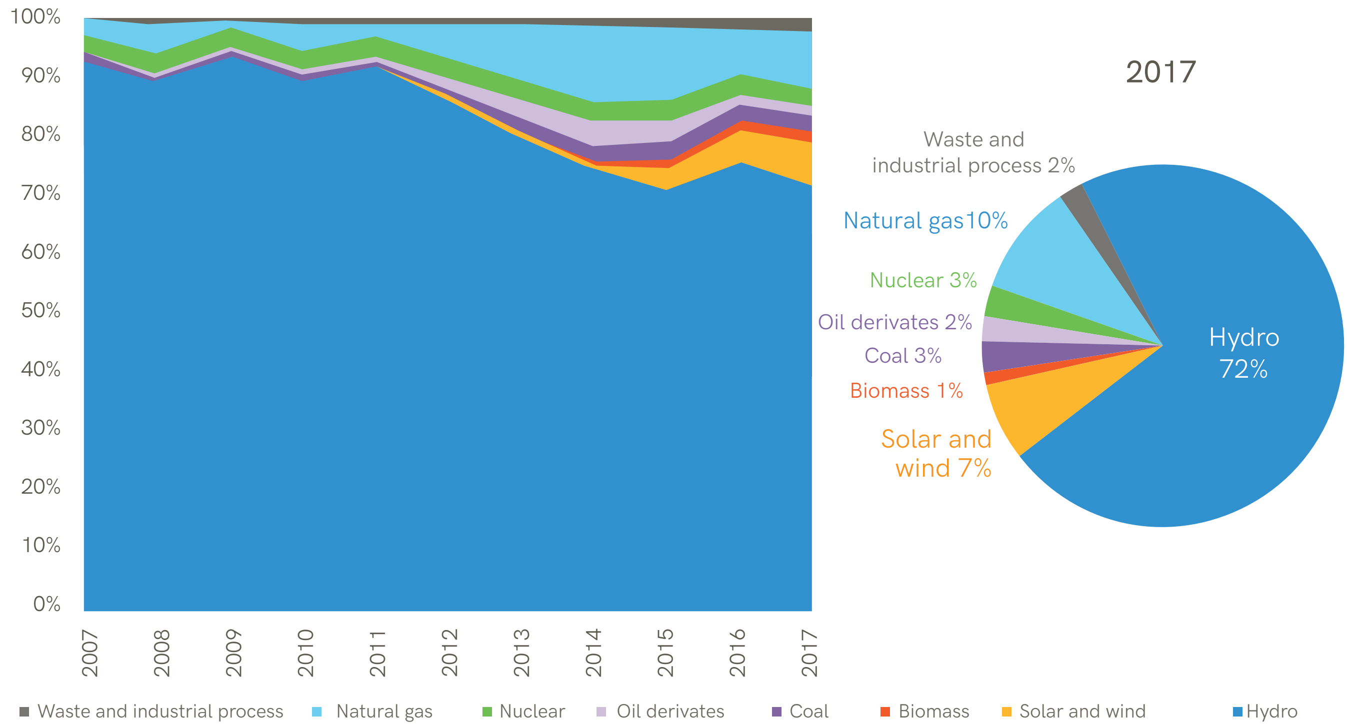

Figure 2-10 | **Domestic supply of electric power by source (Aneel, 2018)**[19]

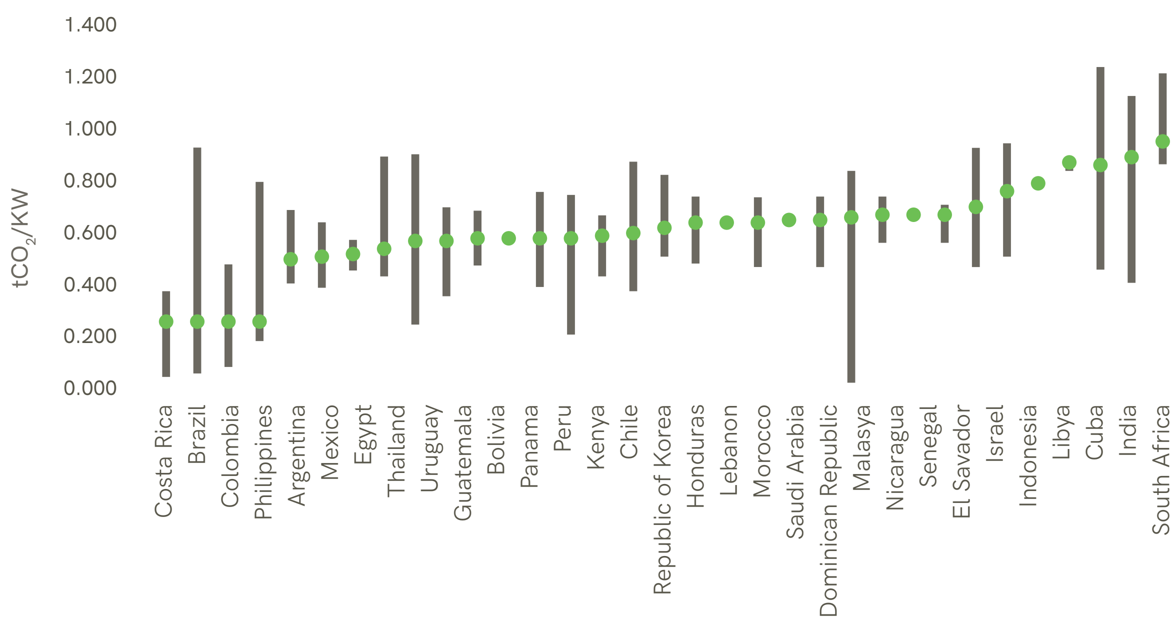

Figure 2-11 | **CO_2 emission factor of electric power generation (IGES, 2018)**

[19] This considers the volume of energy load sent out by the generating plants centrally through the National Interconnected System (SIN) and electric power produced by the generators not yet integrated into the SIN.

Although hydroelectric generation has shown signs of deceleration in recent years, increased participation of other renewable sources, such as wind and photovoltaic power, is expected to maintain a clean energy matrix in Brazil. According to PDE 2026, the share of renewable sources will remain above 80% of the total installed capacity of the National Interconnected System (SIN) in the period (Figure 2-12).[20]

In the reference scenario adopted in PDE 2026, however, a marginal penetration of EVs in the country was considered (less than 1% up of hybrids and practically zero EVs by 2026). For this demand, the impact on the electricity supply in the SIN would be negligible.

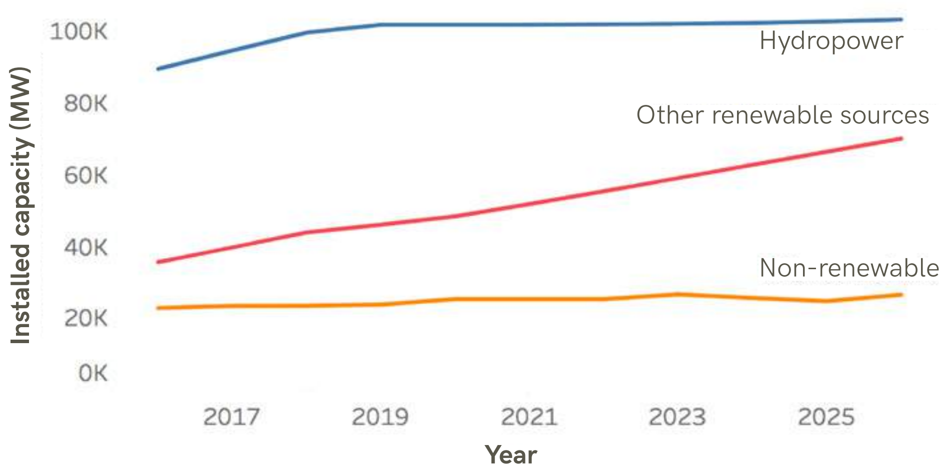

Figure 2-12 | **Evolution of the installed capacity, by electricity generation source, for the reference expansion (MME, 2017)**

[20] SIN is formed by companies from the South, Southeast, Center-West, Northeast, and part of the North regions of Brazil. The Brazilian electricity production and transmission system is a large-scale hydrothermal system, with a strong predominance of hydroelectric plants and multiple owners.

3

CONTEXTUALIZATION OF ELECTROMOBILITY POLICIES FOR BRAZIL

Successful experiences for electromobility indicate the need for coordinated efforts to overcome the technical, economic and infrastructure barriers. In these experiences, the motivating factors for vehicle electrification – when translated into public policies and deployed in actions and programs that complement each other – induce the alignment of different stakeholders. One of the first lessons learned is that, without the clarity of motivation, problem-situation or opportunity identified, it will be difficult for this integration of efforts to occur (Consoni, 2018; Marx & Mello, 2014).

This chapter starts with a summary of key stakeholders in promoting electromobility in Brazil, and continues to describe policies with a direct or indirect effect on electromobility. The same structure of the international policy evaluation in Chapter 1 is followed, with sections for clean vehicle and fuel regulations, consumer incentives, charging infrastructure, and planning, policy, and other promotions.

MAPPING KEY ACTORS

The mapping of the key actors involved directly or indirectly in electromobility provides an idea of the dimension and complexity of the issue (Figure 3-1). The system of governance for EVs in Brazil starts from a characterization of five spheres: the automobile industry, the electricity sector, education and research, the political environment (government), and the innovation environment, which permeates all spheres (Consoni, 2018). In the case of bus electrification, added to these spheres are the urban public transportation service providers, hired by the government.

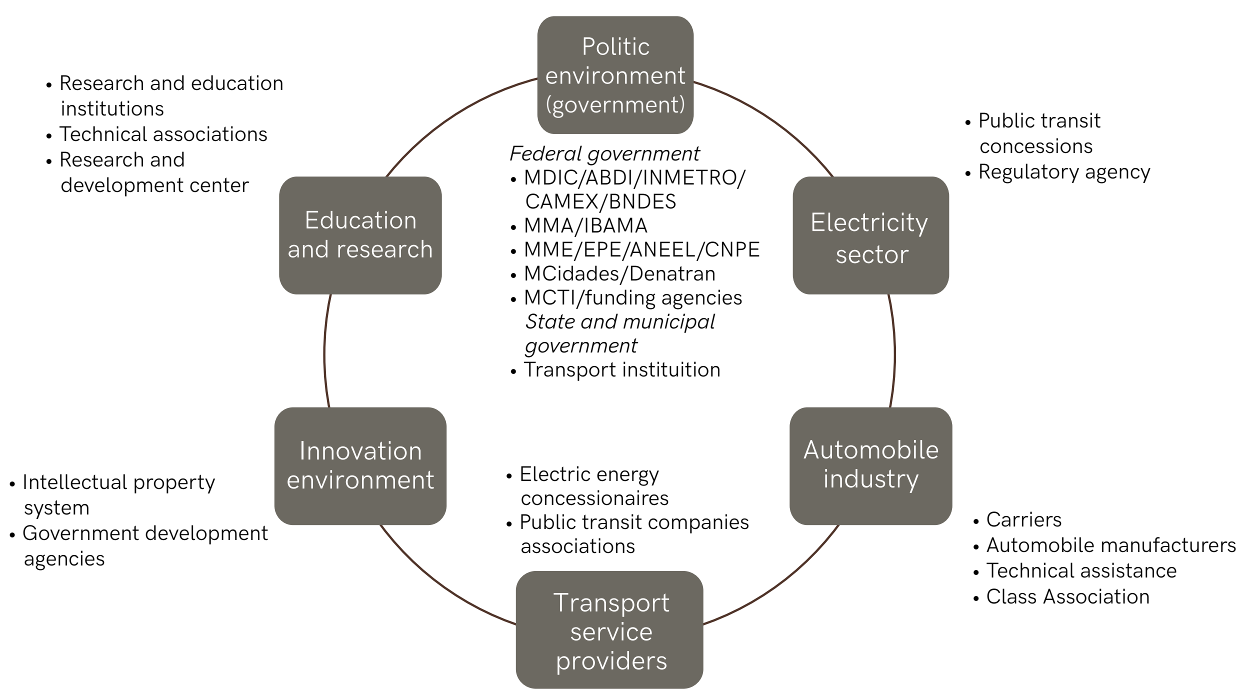

Figure 3-1 | **System of governance for EVs in Brazil**

AUTOMOBILE INDUSTRY AND ASSOCIATIONS

The automobile industry, as a major stakeholder, has taken a conservative institutional stance on electrification, suggesting timid steps toward hybridization at first. Regarding light-duty vehicles, the sector has also positioned itself to defend biofuel as the only domestic solution for the mitigation of GHGs, not always considering the possible complementarity of other solutions. However, there is no unanimity in the industrial sector regarding this position, with pioneering initiatives by some manufacturers in favor of electrification, albeit still incipient, such as Toyota, BMW, and Ford, with products already on the market. In the case of buses, one can see a more promising field, especially for three manufacturers: BYD, Eletrabus, and Volvo.

The auto parts industry has been involved in the discussions on this subject matter in a more incisive way through battery manufacturers and electric motor manufacturers, which naturally perceive a window of opportunity and are moving in favor of electrification.

The role of class associations in this governance is also relevant. This includes the National Association of Automobile Manufacturers (Anfavea), the Brazilian Association of Motor Vehicle Importing and Manufacturing Companies (Abeifa), the Brazilian Electric Vehicle Association (ABVE), and the National Union of the Component Industry for Motor Vehicles (Sindipeças). Considering the historical importance of the automobile sector to the Brazilian economy, these associations maintain a constant dialogue with the government, acting as influencers of public policies.

As a more comprehensive collective representation, the National Association for Public Transportation (ANTP), a non-profit entity focused on the public transportation and traffic sectors in Brazil, is also worth mentioning. Its objective is to develop and spread knowledge geared toward ongoing improvements in public transportation. Its members include government bodies – public transportation and traffic management agencies, public and private operating companies, employers' and employees' unions, manufacturers and service providers, consultants and universities.

URBAN PUBLIC TRANSPORTATION SERVICE PROVIDERS

The primary responsibility for urban public transportation is the municipal government, as established by item V of article 30 of the Brazilian Constitution. The municipal governments, however, generally hire a company to provide this service under a system of concession or permission (licensing), with the responsibility to supervise and control this service. The conditions of such engagements are established in agreements, defined by the government authority. Regarding vehicle technology and emissions, these agreements have been using parameters of maximum and average ages of the fleet to indirectly set the profile for the Program for the Control of Air Pollution from Motor Vehicles (Proconve) phases, associated with emission limits of local effect pollutants. It is also worth mentioning the recent initiative in the city of São Paulo to require compliance with legislation related to targets for reducing GHG emissions and pollutants with a local effect.

Thus, regarding bus electrification, concessionaires and licensees are involved in choosing technologies that are more cost-effective and feasible within the constraints imposed by contractual conditions and legislation.

In a collective manner, public transportation companies are represented by associations, federations and regional trade unions that defend their interests. It is also worth mentioning the National Association of Urban Transportation Companies (NTU), which gathers several regional representatives.

ELECTRICITY SECTOR

The service sector, specifically electric utilities companies, will be directly affected by the electrification of vehicles, both by the increase in demand and the infrastructure required for recharging. Considering the peculiarities of the marketing of electric power in Brazil, with a free market and regulated market co-existing in harmony, the entry of EVs may require the design of new business models, and the concessionaires should be interested in opening new business fronts. Some utilities companies are also being seen investing the mandatory portion of their net operating revenues (0.75%) in projects associated with electromobility.[21]

EDUCATION AND RESEARCH

As this is a subject that involves technological innovation, including disruptive technologies (especially in relation to batteries and fuel cells), the role of educational and research institutions is also relevant. Some institutions have stood out in terms of publications generated, such as the University of São Paulo (USP) and the University of Campinas (Unicamp), which also offer teaching programs related to vehicular technology (Consoni, 2018). Aside

[21] Law 12,212 of December 10, 2010, which amends Law 9,991 of July 24, 2000, established an annual investment requirement for a certain percentage of the Net Operating Revenue (NOR) of electricity utilities companies in R&D.

from universities, research centers associated with the industry deserve special mention. According to Barassa et al. (2017), although in Brazil there are science and technology institutions that develop research relating to electric mobility, such research has been isolated or without general alignment. R&D agencies and funding agencies are important in this context, including CNPq, Fapesp, and BNDES.

Complementing the research centers are the national and international standardization bodies. Rules and standards are part of the process of developing and consolidating new technology. These include entities such as the National Institute of Metrology, Standardization and Industrial Quality (Inmetro) and the Brazilian Association of Technical Standards (ABNT) in Brazil, and international organizations such as the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and the Society of Automotive Engineers (SAE) (Barassa, Moraes & Consoni, 2016).

There is also the Brazilian Association of Automotive Engineering (AEA), a predominantly technical entity whose dynamic is based on the formation of working groups to support the formulation of policies for the sector. Its members are primarily linked to the automobile, auto parts and fuel industries.

FEDERAL GOVERNMENT

In government spheres, there are key players in various areas. For a variety of reasons, they deal with issues that directly or indirectly relate to electromobility. The main ones are listed below.

Ministry of Industry, Foreign Trade and Services (MDIC) plays the role of formulator, executor and assessor of public policies for the promotion of competitiveness, foreign trade, investment and innovation at businesses, as well as consumer welfare. With the aim of stimulating the competitiveness of the industry, it has promoted discussions on the topic of electromobility within the scope of the new industrial policy for the automobile sector, Rota 2030.

Brazilian Industrial Development Agency (ABDI) is linked to the MDIC and was created in 2004 to promote the implementation of industrial policy, aligned with science, technology and foreign trade policies. It has participated in the design of public policies through cyclical, strategic, and technological studies on various sectors. In terms of electromobility, it has carried out specific studies related to the technology, its value chains and other connected topics, such as smart grid.

National Institute of Metrology, Standardization and Industrial Quality (Inmetro) is a federal authority linked to the MDIC, which acts as Executive Secretariat of the National Council of Metrology, Standardization and Industrial Quality (Conmetro), an interministerial body that is the regulatory arm of the National System of Metrology, Standardization and Industrial Quality (Sinmetro). It is involved in the standardization of products and components (connectors, for example) associated with EVs.

Chamber of Foreign Trade (Camex) is an integral part of the Government Council of the Presidency of Brazil, and its objective is to formulate, adopt, implement and coordinate policies and activities related to foreign trade in goods and services, including tourism. It is composed of the Minister of Development, Industry and Services, who serves as the chairman of Camex; the Chief of Staff of the Presidency of Brazil; the Minister of Foreign Affairs; the Minister of the Treasury; the Minister of Agriculture; the Minister of Planning, Budget, and Management; and the Minister of Agrarian Development. Among its attributions is to set import tax rates for EVs. In 2015, for example, it exempted the import tax from these vehicles (Camex Resolution 97), which up to that time had added 35% to the total value of the vehicle. It also reduced the import tax on hybrid vehicles. According to information obtained on the agency's website, the decision to reduce this tax was made to put Brazil on new technological paths, providing consumers with vehicles with high energy efficiency, low fuel consumption, and reduced emission of pollutants. Such measures are aligned with the policy of encouraging new technologies to propel and attract new investments for domestic production of these vehicles.

National Economic and Social Development Bank (BNDES) is a federal public company associated with the MDIC, the primary objective of which is to finance initiatives that contribute to Brazil's national development. The BNDES opened a line of financing for research for electromobility, in addition to managing the resources of the Climate Fund, which provides lines of lower-interest financing for the acquisition of buses with clean technology and production capacity for manufacturing these vehicles. It also provides a tool developed in partnership with the Getulio Vargas Foundation to estimate the bank's performance in the Climate Fund Program and to calculate the reduction of GHG emissions linked to projects financed by the institution.[22] Among the possible simulations for this tool is the acquisition of electric buses, hybrid vehicles, other models with electric traction or powered by biofuels.

[22] Available at https://www.bndes.gov.br/wps/portal/site/home/financiamento/produto/fundo-clima/ferramenta-calculo-reducao/

Ministry of Science, Technology, Innovation and Communications (MCTIC) establishes, among other topics, the national policy of scientific research, technology and innovation. This Ministry's 2016/2019 National Science, Technology and Innovation Strategy includes technological initiatives of renewable sources, smart grids, electric vehicles, new batteries, biofuels, and intrinsically safe modular nuclear reactors. Therefore, it has strong interface with the development of skills and technologies for EVs. This ministry also has funding agencies for studies and related projects. Another interface with this issue at the MCTI refers to its coordination of the Options for Mitigation of Greenhouse Gas Emissions in Key Sectors of Brazil project, with resources from the Global Environment Facility (GEF) and in partnership with UN Environment. This project aims to support decision-making on actions that potentially reduce GHG emissions in key sectors of the economy. The interface with electromobility, in this case, is due to the possibility of modeling mitigation scenarios with vehicle electrification, also adding cost-benefit analyses.

The **Ministry of the Environment (MMA)** has the mission of formulating and implementing national public environmental policies in an articulated manner, agreed upon with public actors and society for sustainable development. Within its attributions, this Ministry emphasizes its role in the governance of the National Plan on Climate Change and the National Air Quality Plan (PNQA). One of the instruments of the National Policy on Climate Change is the National Climate Change Fund. It is through this resource that lower financing rates, for example, are offered for electric and hybrid buses, a program operated by BNDES.

The MMA also has an interface with electromobility in an indirect way, regarding motivating factor air quality. The ministry formulates policies for institutional support and strengthening to the other agencies of the National Environmental System (Sisnama)[23], responsible for carrying out local actions geared toward air quality management.

Through its Air Quality Management division, the MMA is responsible for proposing, supporting and evaluating studies and projects relating to the preservation and improvement of air quality, implementing programs and projects in its area of operations, technically assisting other government agencies that deal with these issues (Conama and Contran), as well as preparing reports and technical notes on matters within its competence. Also noteworthy are this division's programs for specific sources, such as National Programme for Control of Air Quality (Pronar), Proconve, National Program for Control of Air Pollution by Motorcycles and Similar Vehicles (Promot), and support to states for the elaboration of Vehicle Pollution Control Plans (PCPVs) and Vehicle Inspection and Maintenance (I/M) Programs, according to Conama Resolution 418/2009.

Brazilian Institute of Environment and Renewable Natural Resources (Ibama) is an agency linked to the MMA, the attributes of which include the implementation of national environmental policies, especially the coordination of the Proconve. Through this program, maximum vehicle emission limits are required, in addition to the approval of vehicles.

Ministry of Mines and Energy (MME) is the formulator of public policies relating to energy. It coordinates the Brazilian Program of Technologies and Emissions, an interministerial program that aims to promote scientific studies on the influence of fuels and vehicle technologies on automotive emissions. It also aims to obtain air quality mapping and modeling, which can help industry and public agencies in public policy making and decision-making on fuel quality and air quality, public health, and mobility in large cities. By its attributes, this program would have an interface with electromobility, but according to the minutes of meetings, it is focused on biofuels. Also participating in the program, in addition to the MME, are the Ministry of the Environment (MMA); the National Agency of Petroleum, Natural Gas and Biofuels (ANP); Ibama; Petróleo Brasileiro S.A. (Petrobras), and the Brazilian Association of Automotive Engineering (AEA). MME also coordinates the newly launched RenovaBio, a state policy aimed at outlining a joint strategy to recognize the role of all types of biofuels in the Brazilian energy matrix. The program targets both energy security and GHG mitigation, and therefore has an indirect interface with electrification.

With the aim of meeting the targets established in the National Energy Plan 2030 (PNE 2030), through a collective effort with several agencies coordinated by the MME, the National Energy Efficiency Plan (PNEF) was prepared (MME, 2012).[24] Among the lines of action proposed directly related to the issue of electromobility, the following is most prominent: to study incentives such as subsidies or rate benefits for the entry of individual EVs, also including studies of topics related to regulation in the electric sector.

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[23] Sisnama, instituted by Law 6,938 of August 31, 1981, regulated by Decree 99,274 of June 6, 1990, is composed of the agencies and entities of the Federal Government, State/Federal District Governments, Municipal Governments, and by public foundations, responsible for protecting and improving environmental quality.

[24] The following entities participated in the preparation of this document: Inmetro, the Energy Research Company (EPE), Petrobras (Conpet), Eletrobras (Procel), and the Electrical Energy Research Center (Cepel), among others. Also, nearly 100 professionals participated directly, and the document was submitted to a process of public consultation.

In the role of formulator of the National Energy Policy, the MME has sought to broaden the debate around the PNE 2050 long-term plan with different government agencies to harmonize sectoral policies and plans. Within this horizon, issues relating to electromobility should be addressed by the impact on the energy matrix, according to the premises to be adopted.

National Electric Energy Agency (Aneel) is an authority linked to the MME, created to regulate the Brazilian electricity sector. It is structured to guarantee security of supply, incentivize generation expansion, diversify the energy matrix, and meet consumer demand at the lowest cost. In 2016 and 2017, it launched public consultations with the aim of obtaining subsidies for improvements in the rate structure and to evaluate the impacts associated with charging EVs. One of the premises presented by the agency is to stimulate the creation of recharging infrastructure without cross-subsidies with the current energy consumer, therefore not burdening the energy rates with investments that may be necessary for the EV recharging infrastructure. The results have not yet been disclosed, but the regulation will allow for the creation of a competitive market for the recharging service, co-existing with the current regulated electricity market. Another one of Aneel's recent initiatives that can stimulate vehicle electrification with the lowering of electricity costs is the adoption of differentiated rates according to the time of day and day of the week, having higher rates at times when energy demand is normally higher. This is about creating the "white rate," in force since January 2018, an indication of the beginning of the development of the smart grid.[25]

Energy Research Company (EPE) is a federal state-owned company that aims to provide services to the MME in the area of studies and research geared toward subsidizing the planning of the energy sector, including electric power, oil and natural gas and their derivatives, as well as biofuels. In its publications, plans and presentations, it has positioned itself as non-favorable to the accelerated electrification of vehicles in Brazil, highlighting the role of biofuels as a vehicle energy solution for decarbonization.

National Council on Energy Policy (CNPE), chaired by the minister of Mines and Energy, is an advisory body to the president of Brazil for the formulation of energy policies and guidelines. It has the attribute of proposing national policies and specific measures to the president of Brazil, aimed at promoting the rational use of the nation's energy resources.

Ministry of Cities (MCid) was created with the aim of combating social inequalities, transforming cities into more humanized spaces, and expanding the population's access to housing, sanitation, and transportation. It outlines directives for the implementation of the National Mobility Policy, guides the implementation of mobility plans in cities, and provides lines of financing for infrastructure or equipment that may be linked to conditioning factors, such as the stimulation of low carbon technologies.

National Transit Department (Denatran) is Brazil's highest executive transit authority, responsible for coordinating the National Transit System. This agency, linked to MCid, is in the process of establishing the regulation on EVs for the purposes of evaluating the structural and electrical safety of these vehicles. Contran Resolution 717 of November 2017 establishes a period of six months (expiring in mid-2018) to carry out technical studies for such regulation.

STATE GOVERNMENT

As the States are responsible for inter-municipal transportation, competent state agencies take the lead in assessing and demonstrating initiatives to stimulate low-carbon technologies. For example, the São Paulo Metropolitan Transportation Company (EMTU) has been testing the Eletrabus electric bus since 2013 for a distance of 11.5 km. This bus has rechargeable lithium-ion batteries, and the operation was planned with quick recharges at the Diadema terminal, as well as slower overnight recharges in the garage. EMTU's fleet also has 14 hybrid vehicles (13 standard type buses and one articulated bus), having started with these vehicles in 2003, and 80 trolley-buses that cover 4.5 million kilometers annually (Sistran, 2014).

State environmental legislation, especially as related to climate change, can also induce electrification of the bus fleet.

Some statewide financing lines are available to replace fossil fuels. For example, Desenvolve SP, a financial institution of the State of São Paulo, offers financing such as the Green Economy Line, linked to sustainable practices, such as the replacement of fossil fuels with renewables.

[25] The white rate was established by Normative Resolution 733 of September 6, 2016 and entered into force in January 2018. It is offered for consumer units that are served at low voltage (127, 220, 380 or 440 Volts), known as Group B. Consumers opt for the white rate or conventional rate, according to their consumption profile. This initiative should not be confused with the "rate flags," applied compulsorily to consumers according to the conditions involved in the generation of energy (Normative Resolution 547 of April 16, 2013). In this other situation, through the establishment of green, yellow and red flags, the consumer is shown the variation in the rate of the month as a function of the variable costs of generating energy. Thus, when there is a water crisis and thermoelectric plants enter operation, for example, a higher rate is applied, indicated by the colors yellow or red. The lowest rate corresponds to the green flag.

Some state taxes and fees can be lowered according to technology, which are also examples of state attribution. An example of this is the state tax on motor vehicle ownership (IPVA). In seven Brazilian states (Rio Grande do Sul, Maranhão, Piauí, Ceará, Rio Grande do Norte, Sergipe, and Pernambuco), there is a total tax exemption for EVs, and in three (São Paulo, Mato Grosso do Sul, and Rio de Janeiro), the rate is lower (ABVE, 2018).

MUNICIPAL GOVERNMENT

In Brazil, there are 5,570 municipalities, 42 of which have over 500,000 inhabitants (IBGE, 2018), and 3,313 of which have an organized city bus system (NTU, 2018). The entity primarily responsible for urban public transportation management in Brazil is the municipal government. To carry out this attribute, transportation companies provide services under a system of concession or licensing and are engaged through a bidding process. These services are detailed and overseen by the competent municipal agency, which will also invest in infrastructure, and plan urban mobility.

Some municipalities establish specific legislation on mitigation of the effects of climate change, in some cases setting overall emission reduction targets, or detailing targets for reductions for collective transportation. In these cases, even without specifying vehicle technology to meet these targets, the solution may include electromobility. This is the case of São Paulo (Law 14933/2009, amended by Law 16.802/2018), and Belo Horizonte (Law 10175/2011).

Other actions at the municipal level include monitoring by city governments, usually through their transportation secretariats, testing or demonstration of low-emission technologies, or launching of programs for the development or promotion of these technologies.

CLEAN VEHICLE AND FUEL REGULATIONS

The main regulations relating to clean vehicles and fuels are established at the federal level, the most prominent of which – for this study – are Proconve, focused on the environment, Inovar-Auto, and Rota 2030, under the aegis of industrial competitiveness.

PROGRAM FOR THE CONTROL OF AIR POLLUTION BY MOTOR VEHICLES (PROCONVE)

Proconve has induced technological transition in vehicles in Brazil since its creation, in 1986, aiming at reducing emissions of air pollutants and noise. Coordinated by IBAMA, the program has been working to control vehicular emissions of CO, NMHC, NOx, and PM, pollutants of local effect. Its premise is the establishment of more restrictive limits of emissions, leaving it up to manufacturers or importers to choose the most cost-effective limits. This program, in its current stages, does not set limits for CO_2 emissions and therefore would not induce electrification. However, there is a proposal currently in public consultation to include this pollutant in Proconve regulations, which – although still in the early stages – could be a major step towards zero exhaust emissions.

INOVAR-AUTO AND ROTA 2030

In order to encourage specific sectors of the economy, and general sectors linked to the manufacturing industry, the government establishes a set of instruments under the framework of industrial policy. In the scope of recent industrial policies, such as Inovar-Auto, launched in 2012 and terminated in 2017, the MDIC sought to increase competitiveness through instruments that would induce manufacturers to produce safer, more efficient and more technologically advanced vehicles, as well as attract investment. In this policy, targets were established for energy efficiency in light-duty vehicles, as well as minimum investments in R&D, engineering, and basic industrial technology. At the end of the period, in compliance with the program's goals and targets, manufacturers or importers would be entitled to presumed tax on industrialized products (IPI) credits of up to 30% on vehicles produced in the period, plus presumed IPI credit for expenditures on R&D and investments in basic industrial technology, production engineering, and supplier training.

Under the program's rules, in order to stimulate the production of hybrid and electric vehicles, additional credits were established for these technologies, or 'super-credits,' computed in calculations of corporate energy efficiency, similar to international policies.[26] Despite the super-credits, the energy efficiency targets in Inovar Auto were not stringent enough to stimulate sales of EVs in the country.

[26] MDIC Ordinance 74 of March 26, 2015 established a weighting factor as a multiplier of license plates issued that, in a simplified form, gives greater weight to vehicles with energy consumption below 1.35 MJ/km. This factor varies from 2.75 to 1.75 according to the energy efficiency range from 2015 to 2017, and 2.5 to 1.5 from 2018 to 2020.

Considering the high participation of the Brazilian automotive industry in the economy, representing 22% of the industrial Gross Domestic Product (GDP) in 2015, the Inovar-Auto program sought to increase the technological level of products and processes of the Brazilian automotive industry through incentives to R&D. However, the program terminated in 2017, and little is known of its effective results. Some studies indicate a failure to meet its main objectives (Consoni et al., 2018; Pascoal et al., 2017). The specific objective of inducing the manufacture of technologically more advanced products was not reached, according to the studies, and no significant advances in this direction were observed. For example, hybrid and electric vehicles accounted for only 0.15% of total new vehicle licensing in Brazil in 2017, and all these vehicles were imported (from Japan, Mexico, Germany, Slovakia, China, and U.S.). Only the BMW i series is electric, evidencing the low supply of such products on the Brazilian market.

With the end of the Inovar-Auto program in 2017, the new industrial policy called Rota 2030 is now being discussed, whereby long-term guidelines for the automotive sector are set. For this new cycle, the incorporation of specific strategies for electromobility has been further discussed. This policy could represent an opportunity that would dictate the pace of electrification in Brazil, triggering coordinated actions of R&D, as well as investments in industry, and leveraging complementary actions, associated with recharge infrastructure, for example.

In energy efficiency, the Inovar-Auto program was focused on light-duty vehicles, so there was no direct action to induce electrification of buses. Rota 2030 will likely not yet be an inductor of heavy-duty vehicle electrification in the short term.

CONSUMER INCENTIVES

Through international experience, consumer incentives have been shown to be important for the introduction of EVs, reducing the initial upfront cost barrier to their acquisition. Several actions have been seen in Brazil in this regard. Table 3-1 summarizes some of these initiatives.

Table 3-1 | **Consumer incentive initiatives in Brazil**

Initiative	Agency	Coverage	Comments
Exemption or reduction of IPVA for electric and hybrid vehicles	State governments[27]	Total exemption: Rio Grande do Sul, Maranhão, Piauí, Ceará, Rio Grande do Norte, Sergipe, and Pernambuco	Muitas vezes, esse é um primeiro passo para traçar uma estratégia de VEs e a implementação das políticas
Exemption or reduction of import tax rates – electric and hybrid vehicles[28]	Camex	Imported products	Electric and hybrid vehicles are import tax-exempt (previously, they were taxed at 35%)
Reduction of import tax rates of parts and equipment intended for the production of electric and hybrid buses[29]	Camex	Imported products and parts	Reduction, under the temporary ex-tariff regime, changing the import tax rates to 2% in order to stimulate investments in innovation
Exemption from the requirements of Municipal "no-drive days"[30]	São Paulo City Government	Vehicles driven in the city of São Paulo	Exemption from the municipal "no-drive days" for electric and hybrid motor vehicles, which can be driven on any day of the week, regardless of the license plate number
More convenient financing conditions	BNDES – Climate Fund	Buses manufactured in Brazil	In the case of electric, hybrid or ethanol-powered buses, there is a line of financing for new domestic vehicles with lower rates and longer repayment terms than those available for traditional buses. Interest rates offered by BNDES – Climate Fund are between 1.0% and 4.8%

[27] Although the IPVA is a state tax, 50% is allocated to the municipality where the vehicle is registered. Therefore, the exemption or reduction decision involves the state and respective municipality, and there may be exemption of only one of the portions.

[28] Camex Resolutions 86/2014, 97/2015, 27/2016, and 125/2016. "Ex-tariff" system, i.e., temporary reduction of import tariff rate.

[29] Camex Resolution 34 of April 20, 2016.

[30] Beginning in October 1997, the Traffic Restriction Program for Motor Vehicles in the City of São Paulo was created through Law 12,490 and regulated by Decree 37,085. The "no-drive day" system determines that vehicles are prohibited from traveling on certain streets and avenues on certain days of the week, from 7 am to 10 am and from 5 pm to 8 pm, according to the final digit of their plate number.

Some of the initiatives identified in Brazil to encourage consumers to buy electric or hybrid vehicles have a still symbolic effect considering their impact for the real reduction of the TCO. This is the case of the reduction or exemption of IPVA, an annual tax charged on the market value of vehicles. The 1% to 4% discount on the vehicle's market value barely interferes with the total cost of the vehicle, higher than conventional combustion engine technology. This is also the case with the municipal "no-drive days." However, these measures open the discussion to more incentives.

In the case of the Import Tax, the reduction of the rate of electric and hybrid vehicles is impressive, representing 35% on the value of the vehicle. Nonetheless, this measure must be analyzed together with simultaneous ones related to the industrial policy in force up to 2017, the Inovar-Auto program. In this policy, the IPI was increased by 30%, with the possibility of a reduction in this proportion if the qualified company met a number of requirements. In other words, the effective advantage of reducing the import tax was conditioned upon the rules of the Inovar-Auto[31] program and the concomitant reduction of the IPI that imposed some restrictions on imports.

Currently, in a scenario of uncertainty regarding the new industrial policy, it can be affirmed that the tax rates on industrialized products act as a disincentive to hybrid or electric technology. This is because light-duty vehicles with these characteristics have an IPI of 25% on the vehicle's sale value, similar to vehicles with larger engine sizes. The current Industrialized Products Tax Schedule (TIPI) presents values for this tax between 7% and 25% for light-duty vehicles, according to engine size. Although a reduction of the IPI for electric and hybrid vehicles has been announced recently, there has been no news thus far.[32]

In addition to this initiative, a bill has been discussed in the Federal Senate since 2012 that grants IPI exemption to operations with EVs, including raw materials, parts and packaging used in the production process, as well as imports of electric cars from Mercosur countries (PLS 415/2012 Mercosur).

Regarding public transportation, the tax situation is different. Buses are already IPI-exempt, and imports are generally discouraged by the financing conditions offered. The most convenient financing rates, offered by the BNDES, for example, are applied to new domestic vehicles. But even if it still does not fall under BNDES's financing conditions, the reduction of the import tax defined by Camex Resolution 34 of April 20, 2016 benefited the start of operation of China-based BYD in Brazil, which can import parts and components at a lower cost, for vehicle assembly in Brazil. However, for Eletra – which already had high levels of nationalization –, this reduction of the import tax was practically innocuous. For Volvo, the impact was small, as the company already produced hybrid buses in Brazil with mostly domestic components.

Another major stimulus in the case of buses are the lines of financing with more favorable conditions for electric and hybrid vehicles, with lower interest rates and longer repayment terms. In this line, it is categorized under BNDES financing using resources from the National Fund on Climate Change. This financing is aimed at the acquisition of electric, hybrid and other electric traction buses, new and domestic, in addition to ethanol-powered vehicles. The rates are much lower than those available for financing diesel buses (Finame BK Aquisição e Comercialização), for example.

Although it has potential impact, it is noteworthy that this measure alone may not induce effective electrification, since other factors, such as knowledge of traditional technology, uncertainties related to the operational performance of new technologies, and infrastructure for recharging, require coordination of other measures.

CHARGING INFRASTRUCTURE

As indicated by international experiences, the charging infrastructure is a key factor for the advancement of electromobility. The necessary actions may be related to the creation of private or public infrastructure, and slow or fast charge.

The first steps towards creating this infrastructure can already be seen, although still timid, and include measures related to pilot projects, legislation to define a business model, and technical discussions and standardizations.

With regard to pilot projects and initiatives for installing EV charging stations in Brazil, some examples are:

[31] These rules were censured by the World Trade Organization..

[32] The distortions in the IPI do not affect buses, which are IPI-exempte.

- Project Emotive – The Electric Mobility Program of CPFL, one of the largest companies in the Brazilian electric sector.[33] Among this project's initiatives is a partnership with the Graal network, the largest company of service stations on highways in Brazil, enabling the installation of electric charging stations along the highway system between Campinas and Jundiaí, the nation's first intermunicipal corridor for EVs.
- EV recharging stations free-of-charge in six Brazilian cities (Belo Horizonte, Brasília, Curitiba, Joinvile, Rio de Janeiro, and São Paulo), offered by German automaker BMW. Most of these facilities are installed in parking lots of shopping malls and supermarket chains. Starting next year, the construction of an electricity corridor is planned on the Via Dutra highway, between São Paulo and Rio de Janeiro. The project is carried out in partnership with EDP Brasil, an energy sector company.
- Nissan's partnership with Petrobras and Eletropaulo for supply and chargers, enabling taxi service with the Nissan Leaf in São Paulo and Rio de Janeiro since 2012.
- Project of Fundação CERTI and Celesc Distribuição S.A., within Aneel's R&D program: vehicle charging stations strategically installed between Florianópolis and Joinville to guarantee electric mobility between the main cities of the state, forming the first electric corridor in the South of Brazil.

An important factor for the expansion of the number of vehicle charging stations is regulation. The recharge billing model is being defined by Aneel. After public consultation, this agency should soon disclose the conditions for this service, based on the premise of creating infrastructure with no impact on current energy consumers. In other words, investments and cost of energy for recharging must be fully paid for by this new activity, without cross subsidies.

Another initiative to create infrastructure is House Bill of Law 65/2014, which has already been approved by the Senate Infrastructure Services Commission and is currently awaiting deliberation by the House plenary. This bill establishes the obligation to install recharging stations for EVs on public thoroughfares and in residential and commercial settings. The text establishes that the installation of vehicle charging stations would be carried out only at the request of the owners in buildings (commercial and residential) or on public thoroughfares, with the proper authorization of the local government. The costs, however, would be borne by customers.

Another issue related to vehicle charging stations is the standardization of plugs, which is yet to be approached in Brazil.

In the case of recharging infrastructure for buses, there are technical, financial and institutional issues to be addressed. One of the major advantages of buses in relation to light-duty vehicles, in terms of recharging, is that they have fixed routes with known flows and demands, making it much easier to plan the necessary infrastructure. Technical issues include developments and decisions about recharging in garages, with normal recharging equipment, or opportunity recharges with super-fast recharging equipment that can be installed along the bus routes. These solutions must be compatible with the operation so that there is no negative impact on the level of transportation service. The charging time in each situation will depend on the capacity of the batteries and the recharging equipment, ranging from minutes to hours.

The financing of the recharging stations should be considered in the business model that makes the electric bus or hybrid plug-in feasible. Part of the solution may be the provision of financing of this infrastructure at reduced rates, or the government provision of a public recharge infrastructure at bus terminals or along the bus lines.

PLANNING POLICIES AND OTHER PROMOTIONS

TRADE AGREEMENT BETWEEN MERCOSUR AND THE EUROPEAN UNION

Concomitant with the discussions on industrial policy aimed at stimulating Brazil's competitive position, negotiations for a trade agreement between Mercosur and the European Union are currently in progress. These negotiations are complex and have been developing for decades. Among the topics being discussed is the degree of protection to be placed for domestic industry in the sectors encompassed by this agreement, particularly the automobile industry. It is worth remembering that recent trade tensions between China and the United States add uncertainty to the global scenario. Again, the

[33]This R&D project is aimed at establishing a Real Laboratory of Electric Mobility in the Metropolitan Region of Campinas to allow the collection of data about the applications and implications of the technology, enabling the study and in-depth analysis of the impacts of the EVs on the electric sector, aside from providing for the creation of a culture in electric mobility for the Campinas Metropolitan Region, as well as for Brazil overall.

issue of electrification should be evaluated as a lever of opportunities for Brazil, or at least an important issue in order not to widen the disadvantages of the late introduction of this technology. Europe, a major market, has adopted aggressive targets to reduce vehicle emissions, inducing electrification. Some European countries, such as France and the United Kingdom, further strengthen this path with a ban on combustion engines in the near future. Signs for reduction or restriction of first generation biofuels in the energy matrix have also appeared in Europe. It is up to Brazil to carefully evaluate its competitive advantages vis-à-vis changes in the international scenario, in a short-, medium- and long-term outlook.

Adopting policies to encourage the technological development of the sector and strengthen the competitiveness of local auto parts is a critical factor for Brazil not to miss out on opportunities in international markets.

OTHER PUBLIC POLICIES

Electromobility has permeated discussions at several federal agencies in recent years, reflected in reference documents. Here it is not intended to present an exhaustive survey of these documents, but to revisit them in chronological order to encourage further analysis and follow-up. These are documents of various types, prepared at different times and with diverse objectives, such as exploratory studies, consolidation of sectorial analyses and propositions, governmental directives, and energy plans. Table 3-2 summarizes some of them.

Table 3-2 | **Governmental references for electromobility**

Government agency	Document	Summary
ABDI	Prospective sectoral-automotive study Final report (2009)	Document prepared with the collaboration of several entities, including government agencies, representatives of the automobile industry, and associated sectors. The objective was to draw a vision of the future within a 25-year horizon for the auto industry. It addresses topics such as market, technology, public policies, skills and talents. With regard to electric and hybrid vehicles, the document presents a technological and strategic map that bases the proposition of actions.
MME	National Energy Efficiency Plan – basic premises and guidelines (Portaria 594/ 2011)	Presents guidelines for achieving energy goals in the context of the National Energy Plan for 2010-2030. Lines of proposed actions related to electromobility are: • promote technological development to improve vehicle engines, including options for hybrid and electric motors; • examine a tax redistribution in order to exempt the IPI and IPVA from vehicles that are more energy efficient and/or emit less pollutants; • evaluate incentives, such as subsidies or tariff benefits, for the entry of individual EVs, including studies on regulation in the electric sector.
BNDES	The role of BNDES in the development of the Brazilian automotive sector (2012)	Brings a historical analysis of BNDES' performance in the policies for the automotive sector and presents incentive trajectories in recent years focused on technological innovation. Regarding EVs, the authors understand that, prior to the dissemination of this technology, there should be a hybridization or production of hybrid vehicles, combining combustion and electric technologies.
BNDES	Sectorial Bulletin 41 Hybrid and electric vehicles: public policy suggestions for the segment (2015)	Presents a synthesis of global and national incentives, as well as possible specific public policies by segment of the automobile sector. Also, it classifies these proposals in terms of their administrative sphere, scope, fiscal costs and complexity.
Instituto de Pesquisa Econômica Aplicada (Ipea)	Text for Discussion Environmental and economic impacts of electric vehicles and plug-in hybrids: a literature review (2015)	Offers a brief review of the literature on the costs and benefits of electric vehicles and plug-in hybrid vehicles, with an emphasis on their benefits in terms of GHG emission reduction and local effect pollutants. It concludes that hybrid vehicles, even if they have to overcome technological and cultural barriers, have a great potential not only to raise the energy efficiency of the transport sector but also to contribute to increase the efficiency and reduce the costs of the production of electric energy. According to the author, these vehicles can serve as a bridge between conventional and electric vehicles for technological developments.
MME	PDE 2026 (2017)	Points out that transitions to the new technology of electromobility are usually slow and that, in addition to the initial challenges of market entry, barriers emerge that may counteract the expected gains in scale. It projects a participation of less than 1% of flex hybrid vehicles in the national fleet in 2026.

Issues such as technological development and wide-ranging government incentives are recurrent in these documents, which is to be expected in the case of disruptive technology. Although many themes have been raised and discussed, few concrete actions regarding electromobility have been developed based thereon. Another issue to be highlighted in these documents is the variation in projections concerning the share of hybrid and electric vehicles in the fleets: in one of the first projections presented in the ABDI document (2009), compiled through the participation of several stakeholders, a 15% penetration in Brazil by 2034 is estimated. In the most recent document presented by EPE (PDE 2026), this share is projected to be less than 1% by 2026. It is indeed difficult to determine the future share of these vehicles in the nation's overall fleet, especially in the absence of a clear direction in this sense.

4

DEEP-DIVE ON PUBLIC TRANSPORTATION IN BRAZIL

There is consensus among stakeholders that a near-term priority for electromobility in Brazil should be electric buses. Those would bring a series of environmental improvements, including better urban air quality and public health, less noise, and lower GHG emissions. In addition to environmental benefits, investments in electric urban buses align well with government incentives towards urban mobility and the promotion of public transit over individual motorization.

This chapter presents São Paulo's climate change law, which led to the city's commitment to zero emission buses. It also includes initial estimates of the environmental benefits from bus electrification, an evaluation of new business models for captive fleets of public transportation, and a preliminary assessment of production capacity for electric buses in Brazil.

MUNICIPAL LAW ON CLIMATE CHANGE: THE CASE OF SÃO PAULO

In a pioneering initiative in Brazil and Latin America, Law 14933 of June 5, 2009, which established the Policy for Climate Change in the Municipality of São Paulo, was sanctioned.[34] With comprehensive guidelines, this law established goals of reducing anthropogenic GHG emissions generated in the municipality in relation to the level expressed in the inventory in 2005 by the São Paulo Municipal Government. It also established a series of measures to achieve these goals.

Article 50 of this law defines progressive reductions in the use of fossil fuels of 10% per year. By 2018, all buses in the public transportation system of the Municipality must use renewable fuel. However, in 2017, of the fleet of more than 14,000 buses that are part of the São Paulo public transportation system, only 1.5% met the requirements established by law. The impossibility of compliance was evident; consequently, Law 16.802 of January 17, 2018 was enacted, amending Article 50 of Law 14933. In addition to 10-year and 20-year targets for fossil CO_2 reduction, the new law establishes reduction targets for local pollutants, including PM and NOx, as shown in Table 4-1.

With this law, the city is renewing its public transportation concession contracts, which is expected to accelerate fleet renewal and the introduction of cleaner technologies. For the levels of reduction required, especially with regard to CO_2 from fossil origin, electric or hybrid buses should gradually become part of the fleet, thus being a possible alternative to reach the targets.

Table 4-1 | **Targets for the reduction of tailpipe emissions pollutants established in the São Paulo Climate Law**

Parameter	In 10 years	In 20 years
CO_2 of fossil origin	50%	100%
PM	90%	95%
NOx	80%	95%

Although the requirement for a fleet with zero emissions (from exhaust) has been postponed for more than 20 years, this new law was the result of discussions between various stakeholders and representatives of society and the municipality..

Concomitantly with the enactment of this legislation, the bidding process for the Public Collective Passenger Transportation Service was begun in the city of São Paulo. The documents of the process were submitted to public consultation with the aim of obtaining contributions from society for its improvement and, after this process, the final bidding document.

[34] Similar initiatives have followed; for instance, in Belo Horizonte, Municipal Law 10175 of May 6, 2011, states in article 44 that "municipal programs, contracts and permits for public transportation must consider the progressive reduction of the use of fossil fuels, and a progressive reduction target of at least 10% (ten percent) is adopted each year starting with the publication of this Law".

By analyzing these documents from the viewpoint of emissions reduction, it follows that fulfillment of the targets is linked to the future economic and financial balance of the contract between the concessionaire and the government. A schedule of composition of the fleet is required to be submitted within 120 days after the agreement is signed, in accordance with the Call for Tenders. This may pose a risk to meeting reduction targets if there are no mechanisms to mitigate possible increases in cost from the new technologies. In other words, both the legislation and the Call for Tenders associate the introduction of new technologies with the economic-financial viability. Although this is appropriate, it can be a justification for non-compliance with reduction targets.

According to the current bus fare policy of the municipality of São Paulo, the resources to cover the costs of the public transportation system come from the fares paid by users, subsidies and investments borne by the city government, employers who by law must provide Public Transportation Vouchers to their employees, and other sources, such as traffic fines, advertising, rent, and top-offs of single-fare cards (Figure 4-1).

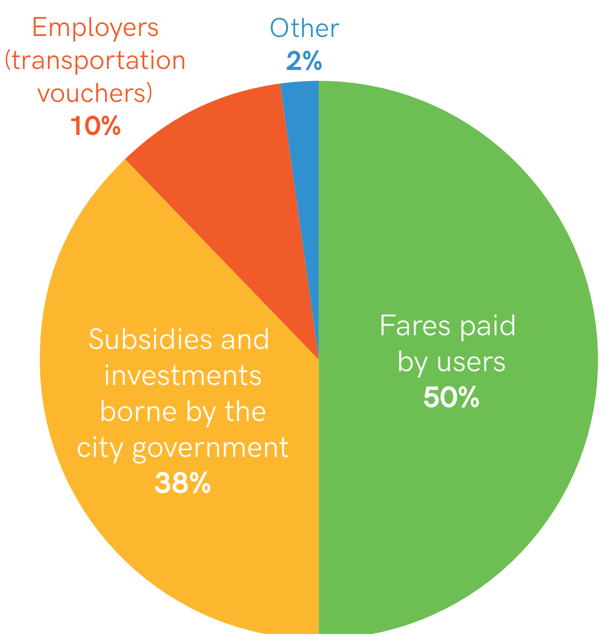

Figure 4-1 | **Sources of funding for the São Paulo public transportation system (SPTrans, 2017)**

Therefore, any increase in costs is usually offset by a larger subsidy from the city government, which depends on defined budget allocations, or by increasing the fare; however, there is tremendous pressure from the populace to prevent this increase, and the matter of keeping bus fares low must always be considered. The search for other sources of financing, although of low representativeness in the set of resources today, may be an option.

There are also contradictory effects on the equation of expenses and revenues caused by the gradual reduction in the number of payers in the system, and thus the proceeds derived from fares. On the other hand, a reorganization of lines is established in the São Paulo Call for Tenders, which is expected to increase the productivity of the system, with a proportional reduction of its costs. The eventual gains of this reorganization, according to the Call for Tenders, must be divided between the government and the concessionaire in equal portions.

The demand for solutions that result in the attainment of targets has been created. The next steps necessarily involve dialogue between government, manufacturers, utilities companies, recharge infrastructure providers, financing and development agencies, and society at large, among others. Tests of new technologies have been conducted and are essential to evaluate their performance under operating conditions, thereby avoiding unforeseen negative impacts on the quality of the service offered, or even the costs thereof. From the lessons learned in successful cases around the world, strategies for mobility are closely associated with comprehensive action plans. These plans should consider aspects such as evaluation of the operational performance of new technologies, assessment of pilot projects and complementary technical studies when necessary, evaluation of the business model, proposal to guarantee the economic-financial balance of concession contracts, analysis and proposal of incentives, and sources of funding to enable innovative low-emission technologies. The local government's role in compiling these plans and in coordinating and monitoring the implementation of activities is essential.

ENVIRONMENTAL BENEFITS OF BUS ELECTRIFICATION

Since one of the priorities of this project is to evaluate electromobility policies for urban bus public fleets, a quantitative evaluation of the potential benefits in terms of climate and local air pollutant emissions from battery electric buses (BEBs) was conducted. These benefits are significant in comparison to the emissions of conventional diesel buses, which currently make up the vast majority of the Brazilian fleet. BEBs are much more efficient than diesel buses, which means less energy needs to be supplied by the fuel in order to move the bus and power auxillary loads. Additionally, the relatively large amount of Brazilian electricity that is produced from renewable generating sources (e.g., hydropower) means that CO_2 emissions associated with the production of electricity needed to power electric buses are lower than in countries that rely on higher emitting generating sources. The combination of these two factors – the higher energy efficiency of BEBs and the low carbon intensity of the Brazilian electricity grid – suggests that scaling up the deployment of BEBs can lead to deep CO_2 emissions reductions and contribute to the decarbonization of the Brazilian transportation sector.

A recent ICCT analysis investigated the degree to which BEB transitions in Brazil can reduce CO_2 emissions from the Brazilian bus fleet (ICCT, 2017). This analysis considered three hypothetical pathways for BEB uptake in Brazil, as shown in Figure 4-2: sales of BEBs could either remain at zero (without BEBs) or grow to reach 100% of new bus sales by 2030 (fast BEBs) or 2035 (moderate BEBs).

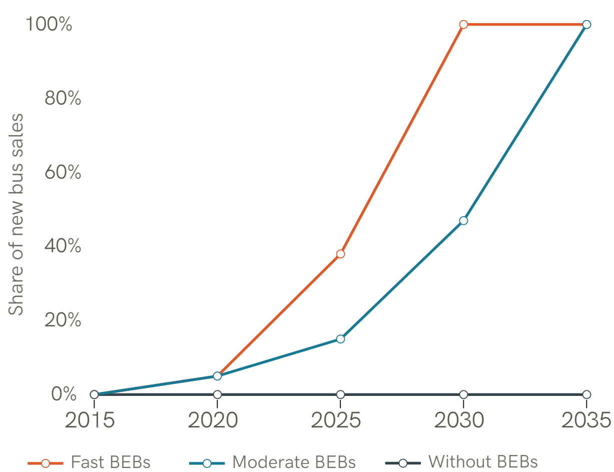

Figure 4-2 | **BEB uptake in Brazil**

This analysis shows that there is a significant opportunity for CO_2 emissions reductions from the electrification of the Brazilian bus fleet. Without electrification, annual CO_2 emissions from the fleet show little change between 2015 and 2040, remaining between 25 and 28 million tonnes per year throughout the 25-year modeling period. In contrast, both electrification scenarios result in significant reduction in CO_2 emissions. Under the moderate BEB deployment scenario, annual emissions in 2040 are reduced by 47% relative to a 2015 baseline, and a cumulative 94 million metric tonnes of CO_2 emissions are avoided relative to the business-as-usual, zero BEB scenario between 2015 and 2040. A faster transition to BEBs, as represented in the fast BEB scenario, yields even greater CO_2 emissions benefits. In this case, annual emissions are projected to fall to 12 milion tonnes per year in 2040, a 57% reduction relative to the 2015 baseline. Cumulatively, 145 million tonnes of CO_2 emissions are avoided between 2015 and 2040 in the fast BEB scenario relative to the case in which there is no uptake of BEBs in the Brazilian fleet. In addition to these reductions in CO_2 emissions, replacing P7 diesel buses with BEBs also significantly reduces emissions of black carbon, a potent short-lived climate pollutant (ICCT, 2017).

Figure 4-3 shows the potential reductions in well-to-wheel CO_2 emissions due to increase in BEBs in Brazil.

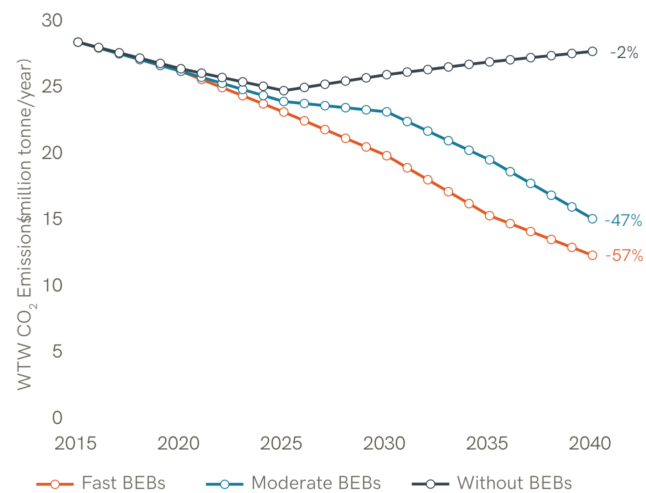

Figure 4-3 | **Effect of BEB uptake on annual well-to-wheel (WTW) CO_2 emissions in Brazil** [35]

CAPTIVE FLEETS OF PUBLIC TRANSPORTATION AND NEW BUSINESS MODELS

The current example of public transportation in the city of São Paulo refers to the broader discussion of financing or new business models to enable the introduction of new technologies in captive public transportation fleets. Public transportation systems must maintain the economic and financial balance so that they do not degrade over time. In order for the scope and qualification of the services to increase, including the introduction of new technologies, new sources of funds need to be considered.

With regard to electromobility in public transportation, some elements have emerged that seek to answer the question of economic and financial balance. It is worth noting that variables such as falling technology costs, the price of electricity and fossil fuels, and new business models contribute to the electrification of public transportation. Some alternatives can be explored:

- **Battery leasing:** one of the solutions that has been presented is excluding the battery from the purchasing cost of electric or hybrid buses, and

[35] Percentages indicate changes in emissions in 2040 relative to baseline, year 2015 emissions for each BEB uptake scenario.

instead incorporating it into a leasing contract or package of services. Batteries can represent more than 1/3 of the total value of the bus, but this will likely decrease over time as technology improves and production increases. Not incorporating the batteries into the cost of the vehicle has increased the competitiveness of these vehicles compared to traditional diesel technology. With this solution, financing is also feasible where a percentage of nationalization of the vehicle is required. Another advantage, aside from contributing to the viability of the new technologies, is the assurance regarding availability to the concessionaire after the life of the batteries, which are replaced with foreseeable and possibly decreasing costs;

- **Maximum Age:** it is possible to lenghten the maximum age for EVs compared to diesel vehicles. Although the justification for this lengthening is technical, associated with the greater durability of EVs, this longer term means that the amortization of the investment is also increased. As an example, in the case of São Paulo, the maximum age of the vehicle is 15 years for the fleet with electric drive, and 10 years for the diesel fleet.
- **Supply of electricity:** a key part for the feasibility of electric traction is the cost of electricity. The action of the government in its dialogue with the regulatory agency and the concessionaires to incorporate the new energy demand of public transportation is important. In this aspect, it is worth mentioning Aneel's actions geared toward improving the rate structure and stimulating the creation of recharge infrastructure. In addition to these initiatives, the recent creation of the "white rate," with reduced prices for certain times of lower demand, also contributes.
- **Combination of solutions:** electric buses and photovoltaic cells in garages for electricity generation (distributed generation). Brazil's short-term energy plans (PDE 2026) includes the generation of electric power by renewable sources including hydroelectric, wind and solar. Solar power generation from photovoltaic cells in garages can accelerate the feasibility of electromobility, in addition to contributing to a cleaner energy mix. This business model should be further explored.
- **New sources of financing for public transportation:** this has been a recurring theme in recent years, with pressure from the populace against fare hikes in Brazil.

The financing of public transportation has been on the agenda, especially in recent years.[36] The pressure to increase the fare, in opposition to the policy of keeping fares low, and the increase of the subsidies to public transportation with the budgetary restrictions imposed upon municipal governments have made the debate even more complex. In this context, discussions about new ways of financing public transportation are re-emerging and may – as an exercise – be added to discussions of the internalization of negative externalities in transportation, both individual and collective. New sources of financing may emerge, based on equity of citizens' access to collective public transportation and mitigation of environmental, social and economic costs of moving people.[37] In this way, discussions on financing go beyond the mere exercise of economic and financial balance vis-à-vis the cost of new technologies, but are included as public policy actions to achieve urban mobility objectives that are more socially equitable and cause less negative externalities.

PRODUCTION CAPACITY FOR ELECTRIC BUSES IN BRAZIL

Without the pretension of deepening the analysis of the productive capacity of EVs, a review of data and public information for electric drive systems in Brazil is presented, with an emphasis on buses.

The manufacture and final assembly of buses comprehends two groups of companies: the chassis manufacturer, involving major manufacturers worldwide, and the body manufacturer, responsible for the final assembly of the vehicle.

For traditional diesel buses, the domestic chassis market has few manufacturers, all foreign-owned companies: Mercedes Benz, with the largest market share, MAN, Volvo, and Scania (Figure 4-4).

[36] Demonstrations and protests that have arisen in Brazil in 2013 against fare increases are emblematic. Based on these movements, the theme of public transportation financing become recurrent. The solutions given at that time largely referred to tax relief or subsidies, but are limited in their ability to continually respond to needs.

[38] These are some of the guidelines and principles of the National Urban Mobility Plan, established by Law 12587/2012.

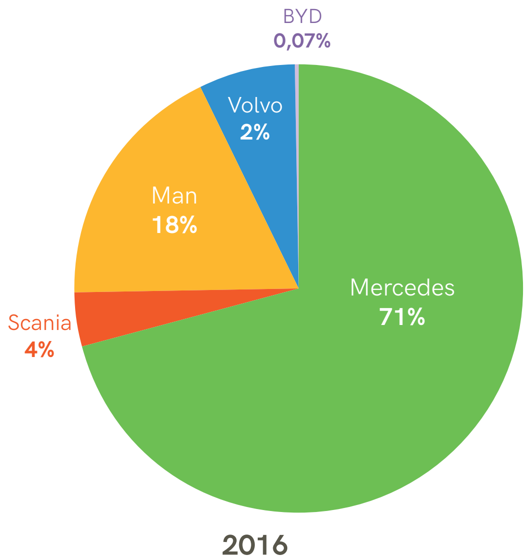

Figure 4-4 | **Market share of buses**

On the other hand, the majority of body manufacturing companies are domestic. The main ones in this segment are Marcopolo/Neobus, Comil, Caio Induscar, Mascarello, Busscar, and Ciferal.

In all, 11,755 new buses were licensed in Brazil in 2017, almost all of which are diesel. This number corresponds to about a third of the new buses licensed in 2011, which reached 34,546 units (Anfavea, 2018). The licensing of electric and hybrid buses is not yet very representative, and there are no consolidated statistics on these vehicles. The manufacture of electric and hybrid buses is limited to three companies, Eletra (São Bernardo do Campo, SP), Volvo (Curitiba, PR), and BYD (Campinas, SP), whose production capacities are shown in Table 4-2.

Table 4-2 | **Current and future installed capacity of electric and hybrid buses in Brazil**

Manufacturer	Current capacity	Planned future capacity
BYD	1 chassis per shift, or around 1,000 chassis per year	If market forecasts materialize, it will expand operations by 2020, installing a second plant, reaching as many as 2,500 chassis per year.
Eletra	1,080 vehicles per year, that is, 90 per month in up to 10 months	It can extend the capacity in 20 months, reaching 200 vehicles per month, as it is a systems integrator. The chassis is supplied by the same manufacturers of chassis for diesel vehicles. The Weg motor would not represent a bottleneck, and the battery is imported.
Volvo	400 hybrid vehicles per year, with a greater or lesser degree of domestic components, according to actual demand	It may expand this capacity, but always according to projected demand. In addition to the hybrids, it has plans to manufacture electric buses in Brazil.

Mercedes Benz, the current leader on the bus market, has not yet made any indication of manufacturing electric buses in Brazil. MAN, the second in terms of market share, and Scania, the fourth, also have no projects for electric or hybrid buses in Brazil thus far. Scania has been testing the technology in Europe, and has a timeline for introducing electric and hybrid plug-ins. It already offers several hybrid products in Europe. MAN has announced the launch of an electric truck developed in Brazil, in partnership with Weg. Mercedes has already started testing with electric trucks with customers in Europe, announcing the goal of reaching mass production by 2021 in that continent.[39]

The capacity of the entire production chain, including parts and components, must be assessed. A critical component for the entire assembly is the battery, which currently is imported. The nationalization of EV batteries is also linked to future demand.

The production of the bodies of these vehicles uses the same installed capacity that already serves diesel vehicles, therefore, would not be a bottleneck to meet the new demand. It is worth mentioning that more than 34,000 new buses were licensed in Brazil in 2014, roughly three times more than were sold in 2017, showing the current idleness in this industry.

The installed capacity for the production of electric and hybrid vehicles, including the manufacture of parts and components, is highly dependent on market projections, because it involves investments. Therefore, estimates of future installed capacity reflect the uncertainties of this market. In a preliminary assessment, considering the installed capacity in Brazil, there do not seem to be major bottlenecks in the production of electric buses. Installed capacity will adapt to new demands if forecasts become firmer. Due to this future demand, investment decisions will define the degree of nationalization of parts and components, including batteries.

[39] According to publication retrieved from https://www.mercedes-benz.com.br/institucional/imprensa/releases/caminhoes/2018/2/20540-mercedes-benz-inicia-testes-com-caminhao-eletrico-nos-clientes

5

TRANSIT BUS ELECTRIFICATION TOTAL COST OF OWNERSHIP ASSESSMENT

This chapter includes the evaluation of the cost to transition the diesel public transport bus fleet in São Paulo to electric drive buses. São Paulo was selected as a case study for the cost of electrification of transit bus fleets in Brazilian cities for a number of reasons. The city has the largest tire-based municipal public transit system in Brazil, with a current fleet of more than 14,000 buses. Additionally, it has recently committed to an accelerated transition to cleaner bus technologies and fuels through the adoption of Law 16.802 (Cidade de São Paulo, 2018). Law 16.802 amends Article 50 of the city's Climate Law and establishes 10-year and 20-year CO_2 and air pollutant emissions reduction targets for the municipal fleet, including public transit buses. This legislation is expected to accelerate the uptake of zero emission electric buses in the city's fleet. Results from São Paulo case study are used to inform recommendations for other Brazilian cities, with a focus on those cost components which bear the greatest relevance to electric drive bus transitions.

This assessment applies a TCO approach to estimate the cost of transitioning the São Paulo fleet to electric drive vehicles. This approach considers both the purchase price of buses and associated infrastructure, as well as operations and maintenance costs throughout the lifetime of the vehicle. The approach is to first estimate the single vehicle TCO of conventional diesel and electric drive technologies for each bus type utilized in the São Paulo fleet. Electric drive technologies considered for the single bus TCO assessment include diesel hybrid-electric buses (HEB), battery electric buses (BEB), and fuel cell electric buses (FCEB). For BEBs, the analysis considers both depot and on-route charging technologies. While the focus of this assessment is on electric drive bus technologies, biofuels play an important role in the Brazilian transportation energy mix. Thus, biodiesel buses are also included in the cost estimates. This analysis assumes that biodiesel buses are certified to Euro VI-equivalent emission standards and fueled with a 100% blend of soy-based biodiesel (B100).

Results from the single bus TCO assessment are then applied to estimate the total lifetime costs of transitioning the entire São Paulo public transport bus fleet to select alternative technologies, including diesel HEBs, depot-charging BEBs, and biodiesel buses. This analysis considers the cost of completing the transition within 10-years, roughly corresponding to normal fleet replacement rates, and within 5-years, representing an accelerated transition. In both cases, cost estimates are compared against a baseline scenario, in which all new bus purchases are assumed to be diesel buses certified to current national emission standard for heavy-duty vehicles, Proconve P7. Each procurement scenario includes total lifetime climate pollutant emissions (GHGs and black carbon). Monetized health and climate damages from these emissions are evaluated to explore the impact of including social costs on TCO assessments.

A sensitivity analysis is presented to explore the influence of individual cost components on TCO estimates and to account for uncertainty in underlying data and assumptions.

TOTAL COST OF OWNERSHIP APPROACH

Existing procurement and contracting practices often favor or require the bus technology option with the lowest purchase price. Purchase price, however, is a poor measure of the total cost of owning and operating a vehicle: over a 10- to 15-year service life, operating and maintenance costs will amount to several times the purchase price of a conventional diesel bus. Using purchase price as the metric for cost also biases such comparisons against hybrid, battery electric, and other bus technologies that have a higher purchase price, but lead to substantially reduced operating and maintenance costs, and, in some cases, lower net costs over the lifetime of the bus (Miller et al., 2017).

A better metric for comparing the costs of bus technologies is TCO, also known as life-cycle cost. TCO is defined as the sum of the costs to acquire, operate, and maintain the vehicle and its fueling infrastructure over a period. Table 5-1 summarizes the components of TCO that are considered for this analysis. Because the objective is to evaluate those costs that depend on the selection of bus technology, some components—such as administration, staffing, license and registration, and insurance—are not evaluated. Including those costs would not be expected to change the outcome of this analysis.

Table 5-1 | **Components of TCO (Miller et al., 2017)**

Category	Component	Definition
Bus and infrastructure purchase	Down payment	Initial cash outlay for bus or infrastructure purchase. The remainder is assumed to be covered by a loan.
	Loan payments	Principal and interest payments over a specified loan period.
	Resale value	If the duration of the planned operation is shorter than the bus service life, this positive cash flow considers the resale value of the depreciated vehicle.
Operations and maintenance	Fueling	Annual cost to fuel the vehicle, determined by fuel efficiency, distance traveled, and fuel price.
	Other operational	Includes the cost of ARLA 32 for diesel and diesel-electric hybrid buses with selective catalytic reduction systems.
	Bus maintenance	Cost of regular bus maintenance. Includes tires, parts, lubricants, etc. Does not include personnel costs.
	Infrastructure maintenance	Where not already included in the retail fuel price, includes the cost of infrastructure maintenance and operations.
	Bus overhaul	For bus purchases that do not include a warranty for the service life of the vehicle, a major mid-life overhaul would include the cost of battery replacement for electric buses and engine overhaul for other buses. For the baseline analysis, battery warranties are assumed to cover the bus operating life.

This work considers a transit bus emissions and cost model which has been developed by the ICCT using detailed inputs for the current São Paulo diesel bus fleet, including information on fleet distribution by bus type and age, annual bus activity and fuel consumption, bus purchase prices, fuel costs, and maintenance costs (e.g., tires, lubricants, parts and accessories). A literature review was conducted to supplement the core São Paulo data set with similar information for alternative technology buses. Data sources and modeling assumptions are further described in the following section.

FLEET OVERVIEW AND DATA SOURCES

This section provides an overview of the data sources used to quantify inputs for TCO and emissions modeling.

FLEET OVERVIEW

Information on the São Paulo fleet, including the total number of buses by type and scheduled annual activity, is taken from the recently issued public notice for the revision of public transport system concession bidding requirements in this city (Prefeitura de São Paulo Mobilidade e Transportes, 2017). This notice introduces new bidding requirements for concessions and includes provisions for the modernization and reorganization of the transport system. Also, it makes detailed projections for the fleet composition and scheduled activity following system reorganization. These projections are used for cost and emissions modeling, as they are the best available representation of fleet characteristics over the 5-yr and 10-yr modeling periods considered here. The projected fleet size and scheduled activity by bus type following system reorganization are shown in Table 5-2.

Table 5-2 | **Projected composition and scheduled activity for São Paulo municipal public transit bus fleet following system reorganization (Prefeitura de São Paulo Mobilidade e Transportes, 2017)**

Bus type	Vehicle length (m)	Minimum seats (#)	Buses in fleet (#)	Scheduled annual activity (million km/yr)	Scheduled annual activity per bus (km/yr)
Miniônibus	8.4-9.0	20	655	30.9	47,160
Midiônibus	9.6-11.5	23-33	2,810	165.6	58,920
Básico	11.5-12.5	35	2,155	143.1	66,400
Padron LE	12.5-15.0	32-38	3,964	281.2	70,930
Articulado LE*	18.3-21.0	34-37	1,569	130.7	83,300
Articulado (23m)	23.0	57	1,535	117.5	76,570
Biarticulado	≤ 27.0	47	30	2.3	76,070

**Articulado (21m) buses grouped together with Articulado LE buses.*

The fleet replacement cost modeling assumes alternative technology buses can deliver the same performance as a conventional diesel bus; therefore, there is no change to the total fleet size with transitions to alternative bus technologies. While this assumption is reasonable for biodiesel buses and diesel HEBs, it is uncertain whether commercially available BEBs would be able to provide a one-to-one replacement for diesel buses across all routes in the São Paulo transit system. This analysis assumes BEBs are deployed first on shorter routes and provide a one-to-one replacement for diesel buses. Over time, as battery costs decline, it is assumed manufacturers will increase the installed battery capacity of BEBs, and thus increase the range and suitability for one-to-one replacement of diesel buses over all route types.

P7 DIESEL BUS COST DATA

This assessment assumes P7 diesel buses are equipped with air conditioning as the baseline technology against which costs for electric drive buses are compared. Detailed financial information on the costs of operating the public transportation system in São Paulo is reported annually by SPTrans in support of evaluations of and adjustments to the tariff rate (SPTrans, 2018). The analysis uses this information to define key cost modeling inputs and operational characteristics (e.g., fuel consumption) for baseline P7 diesel buses. These data are summarized in Table 5-3.

Table 5-3 | **TCO modeling input data for P7 diesel buses equipped with AC (SPTrans, 2018)**

Bus type	Vehicle purchase price (R$)	Maintenance cost (R$/km)*	Fuel consumption (DLE/100 km)
Miniônibus	281,988	0.458	35.1
Midiônibus	367,758	0.563	46.8
Básico	377,816	0.565	52.9
Padron LE	546,073	0.769	63.3
Articulado LE	917,854	1.532	80.2
Articulado (23m)	978,256	1.464	84.8
Biarticulado	1,172,768	2.840	90.4

**Includes cost of tires, brakes, lubricants, and parts and accessories. Does not include labor or other staff costs.*

While publicly available data from SPTrans are adequate to define input cost components for conventional diesel buses, the information is limited to bus technologies currently present in the fleet and excludes alternative bus technologies considered in this assessment. Thus, for cost modeling, the SPTrans dataset must be supplemented with assumptions regarding cost components for these technologies.

BUS AND INFRASTRUCTURE PURCHASE PRICE

Bus purchase prices are based on cost data for alternative transit bus technologies compiled by the California Air Resources Board (CARB) in support of the development of the State of California's Innovative Clean Transit Regulation (CARB, 2017a). CARB reports purchase prices for standard, 12 m transit buses, and includes estimates for conventional diesel buses, as well as diesel HEBs, BEBs (on-route and depot charging) and FCEBs. For this analysis, the cost ratio of each electric drive bus type in contrast to a conventional diesel bus was extracted from the CARB dataset. This ratio was then multiplied by the purchase price of a P7 diesel bus (Table 5 3) to estimate the purchase price of electric drive buses in São Paulo. The same ratio was applied to each of the seven bus types used in the municipal fleet. Purchase price estimates for a Padron LE type bus are shown in Figure 5-1.

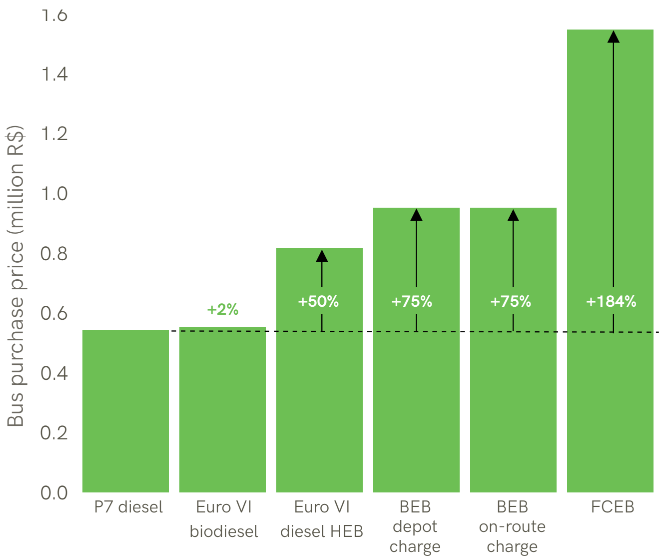

Figure 5-1 | **Purchase price for electric drive transit buses compared to a conventional diesel bus**[40]

This approach assumes electric buses will be available in Brazil at prices relative to diesel buses comparable to rates observed for the U.S. market. In reality, availability and prices of buses will be contingent on what the market provides. Given local financing requirements, Brazilian operators will have greater access to finance for the battery-electric buses produced nationally. Therefore, without investment among more original equipment manufacturers in zero emission bus production in Brazil, the access to a wide array of options may be limited, and the prices of existing options may be relatively high compared to other regions.

The base assessment does not account for anticipated long-term changes in the costs of alternative technologies relative to conventional diesel, due to, for example, reductions in the cost of batteries for BEBs or any economies of scale (CARB, 2016a). The effect of projected decreases in the price of a BEB relative to a diesel bus is explored further in the sensitivity analysis. The analysis also considers the case where the price for BEBs used in the base assessment is underestimated for the Brazilian market.

Infrastructure costs are similarly derived from estimates from CARB. The analysis assumes that no additional infrastructure is required for the transition to diesel HEBs or biodiesel buses. BEBs can either be charged on route (while in operation) or at a bus depot (i.e., during breaks in service or overnight). Each charging technology has advantages and disadvantages with respect to operation and cost. CARB estimates equipment and installation costs for a 50 kW depot charger servicing one bus at 50,000 USD (CARB, 2017a). The same study estimates equipment and installation costs for a 500 kW on-route charging system servicing 6 buses to be 600,000 USD, or 100,000 USD per bus. The actual costs incurred by bus operators, however, depend on the purchase or leasing agreement. Some manufacturers such as BYD include the cost of depot chargers in their bus price. This analysis applies one-time costs of R$161,000 per bus for depot charging infrastructure and of R$322,000 per bus for on-route charging infrastructure (CARB, 2017a). The analysis does not include any land acquisition costs that may be incurred for charging infrastructure due to the lack of detailed local information for this cost component. Nor does the analysis include potential costs of upgrades to grid distribution infrastructure incurred by large scale transitions to BEBs, as it is unclear as to whether these costs will be borne by fleet operators or by utilities.

For FCEBs, it is assumed that a 40-bus hydrogen refueling station costs 5.05 million USD (CARB, 2017a). This results in infrastructure costs of R$406,000 per bus for FCEBs.

OPERATING COSTS

Operating costs for transit buses are dominated by fueling costs. The key parameters for determining fueling costs include bus energy efficiency, distance traveled, and fuel prices. This analysis derives estimates for the energy efficiency of biodiesel buses, diesel HEBs, and BEBs from a recent assessment of soot-free transit bus technologies performed by the ICCT (Dallmann et al., 2017). Data presented in a review report of FCEB performance published by the U.S. National Renewable Energy Laboratory were used to derive similar estimates for FCEBs (Eudy & Post, 2017). In all cases, energy consumption for electric drive vehicles relative to conventional diesel buses was extracted and applied to baseline P7 diesel energy consumption values (Table 5 3) to estimate energy consumption values for each bus type in the São Paulo fleet and for each electric drive bus technology. Energy consumption values for a Padron LE type bus used in the base TCO assessment are presented in Figure 5-2.

[40] Values shown for a Padron LE type bus. Ratio of purchase prices for alternative technologies to conventional diesel applied across all bus types. Biodiesel buses are assumed to have the same purchase price as comparable diesel buses, i.e., certified to the same emission control level (Tong et al., 2017).

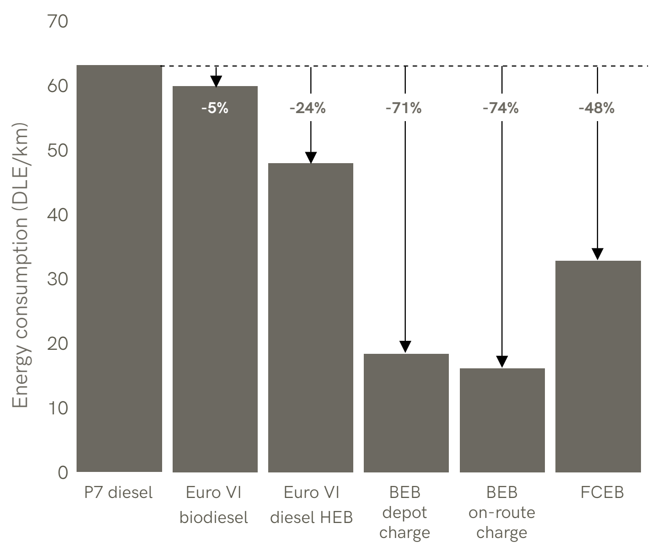

Figure 5-2 | **Energy consumption of electric transit buses compared to conventional diesel buses**[41]

Energy efficiency is highly dependent on duty cycle. For all bus types, efficiency is generally highest for routes with higher average speeds and little stop-and-go driving, such as commuter or suburban routes. Efficiency decreases for routes with lower average speeds and with many starts and stops. The relative energy efficiency across bus technologies also varies by duty cycle. For example, the efficiency benefits of diesel HEBs relative to diesel buses are highest for low- and medium-speed urban routes, but are relatively small, if any, for commuter or suburban routes. This dynamic reflects, in part, efficiency benefits of regenerative braking systems employed in hybrid buses, which recover energy that would otherwise be dissipated. The benefits of these systems are maximized over routes with many starts and stops (Dallmann et al., 2017).

For the base assessment, the efficiency benefits of electric drive bus technologies, as shown in Figure 5-2, represent what one would expect for medium-speed urban routes. The influence of route type on TCO estimates is explored further in the sensitivity analysis.

Prices for diesel fuel and electricity are taken directly from the most recent tariff assessment report published by SPTrans (2018). SPTrans reports a diesel fuel price of R$2.919/L and an electricity rate of R$0.450/kWh for the charging of electric trolley buses. The biodiesel (B100) price used in this analysis, R$2.9807/L, is taken from price data reported for the city of Curitiba municipal transit fleet (Prefeitura Municipal de Curitiba, 2017). Here, the analysis applies the reported diesel and biodiesel prices to estimate fueling costs for P7 diesel buses, diesel HEBs, and biodiesel buses. Fueling costs for depot-charging BEBs are calculated using the same electricity rate as reported for trolley buses. On-route charging BEBs can be subject to higher electricity rates, due to higher demand charges and on peak charging schedules (Gallo et al., 2014). This analysis assumes that, on average, the electricity rate for an on-route charging bus is 1.25 times greater than the rate assumed for a depot-charging BEB (CARB, 2017a). While beyond the scope of this analysis, a more detailed assessment of electricity rate structures and modeling of specific charging strategies for BEB fleets would provide a more accurate estimate of actual fueling costs for both depot-charging and on-route charging BEBs.

For FCEBs, hydrogen fuel costs are taken from CARB (2017a). In the base assessment, fuel prices are assumed to stay constant; a more detailed assessment of the effect of changes in fuel prices on TCO estimates is included in the sensitivity analysis.

In addition to fueling costs, the cost of ARLA 32 is included as an operating cost for P7 diesel, hybrid, and biodiesel buses, which all employ selective catalytic reduction exhaust aftertreatment systems to control NOx emissions (Miller, 2017).

Total per kilometer operating costs for a Pardon LE type bus by bus technology are shown in Figure 5-3.

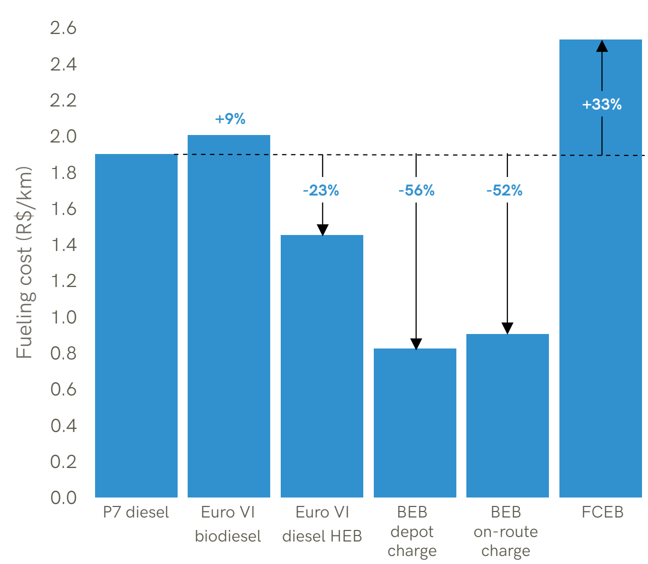

Figure 5-3.| **Operating costs for alternative technology buses compared to conventional diesel buses** [42]

[41] Per kilometer energy consumption is presented in terms of the energy equivalent of a liter of diesel fuel, referred to as diesel liter equivalent (DLE). The relative energy consumption of each electric drive bus type to P7 diesel buses is applied across all bus types. Battery electric bus energy consumption values reported here reflect an assumed 90% charger efficiency and 90% battery charge/discharge efficiency (Bi et al., 2015). On-route charging BEBs are assumed to have an efficiency advantage relative to depot charging BEBs due to reduced battery pack size and, hence, weight (Bi et al., 2015; Tong et al., 2017).

[42] Example shown for Padron LE type bus.

MAINTENANCE COSTS

As mentioned above, per kilometer costs of regular maintenance for baseline P7 diesel buses are taken form the SPTrans tariff assessment report, and include the cost of consumables, such as tires, brake pads, other parts and accessories, and lubricants (SPTrans, 2018).

Relative to diesel buses, diesel HEBs and BEBs offer a number of opportunities for maintenance cost savings. Both technology types apply regenerative braking systems, which reduce brake wear and, in turn, associated brake repair costs. BEB electric drive powertrains are simplified relative to conventional diesel engines and require less regular maintenance (CARB, 2016b). To estimate maintenance costs for electric drive technologies considered in this analysis, a similar approach to what was used to estimate bus purchase price is applied. The ratio of per kilometer maintenance costs for electric drive bus technologies to the maintenance cost for a diesel bus was extracted from the CARB database; this ratio was then applied to baseline maintenance costs estimated for a P7 diesel bus across each bus type in the São Paulo fleet. Per kilometer maintenance cost estimates for each bus technology type are shown in Figure 5-4.

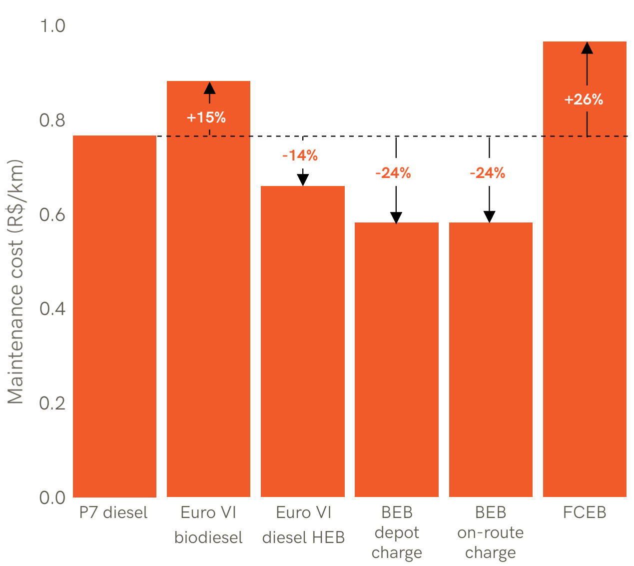

Figure 5-4 | **Regular vehicle maintenance costs for electric drive transit buses compared to conventional diesel buses** [43]

The cost model used in this assessment also considers midlife overhaul maintenance. For diesel and biodiesel buses, this would include any costs incurred for the overhaul of the diesel engine; for BEBs, this covers any battery replacement or upgrade costs. Diesel HEBs may incur costs for both diesel engine overhaul and battery replacement. The base TCO assessment excludes midlife costs. For diesel buses, there is lack of empirical data needed to accurately estimate midlife overhaul costs for the São Paulo fleet. For BEBs, the analysis assumes that battery replacement would be covered under manufacturer warranties, at no additional cost to operators. Some BEB manufacturers, such as BYD, now offer battery warranties or extended warranties that would cover the entirety of the 10-year service lifetime considered in the base assessment. The sensitivity analysis explores how including midlife costs impacts the TCO assessment.

OTHER TCO COMPONENTS

Additional assumptions related to the estimates of TCO in the base assessment include:

- Costs in future years are discounted at a rate of 7% (Akbar et al., 2014).
- A bus service life of 10 years is assumed.
- Financing terms for bus and infrastructure acquisition capital expenses are assumed to be a 50% down payment with the remainder of expenses covered by a loan with a five-year term and real interest rate of 7.6%.
- Depreciation of 8% annually for all bus types (SPTrans, 2018). The value of the depreciated vehicle at the end of its ownership term is treated as a positive cash flow.

The influence of each of these parameters on bus TCO estimates is explored further in the sensitivity analysis.

SINGLE BUS TCO

This section presents single bus TCO estimates. For each bus type utilized in the São Paulo fleet, life-cycle ownership costs are estimated for a conventional P7 diesel bus equipped with air conditioning, as well as each of the alternative bus technologies considered in this assessment – biodiesel, diesel HEB, depot charge BEB, on-route charge BEB, and FCEB.[44] Cost estimates represent the net present value of all modeled costs incurred throughout the assumed 10-year ownership period. Costs in future years are discounted at 7% in the base assessment. TCO

[43] This example is shown for a Padron LE type bus. The ratio of maintenance cost for alternative technologies to conventional diesel is applied across all bus types.

[44] All alternative bus types are assumed to be equipped with air conditioning.

estimates for a Padron LE type bus are presented in Figure 5-5, with a breakdown of the four primary cost categories – net bus acquisition costs, net infrastructure acquisition costs, operating costs, and maintenance costs.

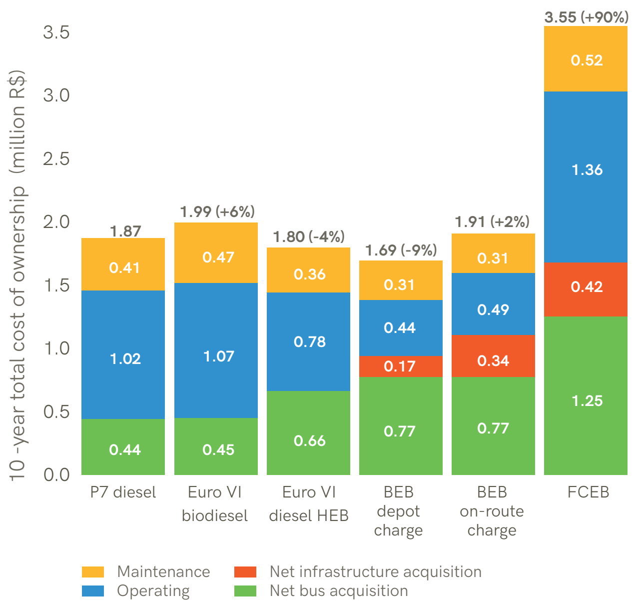

Figure 5-5 | **TCO estimates over 10 years for conventional and alternative technology for Padron LE type buses in São Paulo.**[45]

In the base assessment, the TCO of a conventional diesel Padron LE type bus is estimated to be R$1.87 million. Operating costs account for over half of the total lifetime costs for the diesel bus, with the remainder approximately evenly split between bus acquisition and regular maintenance costs. The cost breakdown for the biodiesel bus is similar to that of the conventional diesel bus, with operating costs accounting for the largest percentage of total life-cycle costs. The higher fueling and maintenance costs estimated for the biodiesel bus result in a slightly greater TCO estimate (+6%) for this technology relative to the conventional diesel bus.

These results show BEBs to be competitive with diesel buses on a TCO basis, with life-cycle costs estimated to be within 10% of those for the conventional diesel bus. The depot charge BEB was estimated to have the lowest TCO of all the technologies considered in this analysis, with life-cycle costs 9% lower than for the diesel bus. Despite the relatively greater vehicle and infrastructure acquisition costs for this technology, reduced operating and maintenance costs lead to overall savings over the operating lifetime of the bus as compared with the conventional diesel bus. The primary cost savings for the depot charge BEB come from reductions in fueling costs, which are about half of those incurred for the diesel bus.

The on-route charge BEB similarly provides significant reductions in lifetime operating costs relative to the diesel bus. The base assessment assumes a higher per bus cost for on-route charging infrastructure relative to depot charging infrastructure. This is the primary contributor to the higher TCO estimated for the on-route charge BEB relative to both the depot charge BEB and the conventional diesel bus. However, even considering the higher capital expenses for infrastructure acquisition, life-cycle costs for the on-route charge BEB are still within 2% of those estimated for the diesel bus.

Like BEB technologies, the diesel HEB provides significant lifetime operational savings compared to the diesel bus. In the base assessment, these savings offset the higher purchase price of the diesel HEB relative to the diesel bus; the sum of vehicle acquisition and lifetime operating costs are approximately equal for the two technologies. Maintenance costs are lower for the diesel HEB, leading to a 4% lower total life-cycle cost than the diesel bus.

Fuel cell electric buses have not reached the same level of technological maturity as other electric drive buses considered in this analysis. As such, capital and operating expenses still remain significantly greater than both conventional diesel buses, as well as diesel HEBs and BEBs. FCEBs are included in the single bus TCO assessment because, over the long term, as this technology is further developed, it is expected to provide a viable zero emission electric option for transit operators. Relative to BEBs, FCEB offer operational characteristics (e.g., operating range and fueling strategies) that are more similar to those of a conventional diesel bus and may provide a more straightforward option for one-to-one replacement. In the near term, high life-cycle costs and low technology readiness prohibit the deployment of this technology beyond pilot or demonstration type projects.

TCO estimates for all bus types are presented in Table 5-4, which shows the life-cycle costs of a P7 diesel bus for each bus type, as well as the cost of each electric drive bus technology relative to the P7 diesel baseline. The life-cycle cost rankings of the different technologies are generally consistent across bus types and similar to what was shown above for the Padron LE bus. With the exception of the miniônibus, the depot charge BEB presents the lowest cost option. For BEBs, it is assumed the same per bus infrastructure costs for all bus types. For smaller buses, with lower vehicle acquisition costs, this means infrastructure accounts for a greater fraction of total capital expenditures and results in relatively higher costs.

[45] Data labels indicate contributions of individual cost components to TCO estimates. Percentages show change in TCO relative to the baseline P7 diesel technology. Acquisition costs include down payment and loan payments minus any bus resale value at the end of the ownership term.

Table 5-4 | **Comparison of TCO estimates across bus types and technologies**

	P7 diesel TCO million R$ (R$/km)	TCO relative to P7 diesel				
		Euro VI biodiesel	Euro VI diesel HEB	BEB (depot charge)	BEB (on-route charge)	FCEB
Miniônibus	0.77 (1.63)	+6.2%	0.4%	11.3%	35.3%	+131%
Midiônibus	1.17 (1.99)	+6.4%	-2.9%	-2.1%	14.6%	+106%
Básico	1.39 (2.09)	+6.4%	-5.4%	-8.9%	5.7%	+95%
Padron LE	1.87 (2.64)	+6.5%	-4.1%	-9.5%	1.9%	+90%
Articulado LE	3.22 (3.87)	+7.3%	-3.7%	-11.4%	-4.1%	+79%
Articulado (23m)	3.11 (4.06)	+7.0%	-2.2%	-8.9%	-1.5%	+83%
Biarticulado	4.14 (5.44)	+8.3%	-2.9%	-9.6%	-3.9%	+75%

UNCERTAINTIES AND SENSITIVITY ANALYSIS

The approach to estimating the TCO for transit buses in São Paulo inherently relies on assumptions made concerning the operational and financial characteristics of both diesel and electric drive bus technologies. For diesel buses, the analysis constrained assumptions using detailed financial information reported by SPTrans. Similar data were not available for alternative technology buses, and the cost and operational data used for these bus types is primarily derived from information reported for these technologies in other regions. The TCO results presented for electric drive technologies in the base assessment are, therefore, representative in so far as the selection of values for cost modeling input variables accurately reflect the Brazilian, and, more specifically, the São Paulo context.

Given these and other uncertainties in the base assessment, it is useful to explore the effect assumptions made regarding individual cost components have on TCO estimates and the relative ranking of technology types. This type of analysis can better characterize the range in TCO one might reasonably expect for each bus technology and helps to identify those components which have the greatest influence on life-cycle costs. This section pursues these questions through a sensitivity analysis of six key TCO modeling input variables: BEB purchase price, energy price, route type, midlife costs, depreciation or resale value, and interest rate.

For each of these input variables, this analysis defines multiple sensitivity cases in which the variable is changed from its baseline value. The single bus TCO is then calculated using the modified input variable, with all other cost modeling inputs set to their baseline levels. For example, the sensitivity analysis assumes BEB purchase prices to be 1.3 and 2 times greater than the purchase price of a P7 diesel bus. All sensitivity cases considered here are summarized in Table 5-5. The sensitivity analysis is limited to Padron LE buses and diesel, diesel HEB, and depot charge BEB technologies. Results for the Padron LE bus and for the depot charge BEB are generally representative for other bus types and for on-route charge BEBs, respectively.

Table 5-5 | **Overview of sensitivity analysis**

TCO component	Sensitivity case	Description
BEB purchase price	Low BEB price	BEB price 1.3 x price of diesel bus
	Baseline	BEB price 1.75 x price of diesel bus
	High BEB price	BEB price 2 x price of diesel bus
Energy price	Baseline	Default diesel fuel and electricity prices
	Energy price +25%	Diesel, biodiesel, and electricity prices 1.25 x default values
	Energy price +50%	Diesel, biodiesel, and electricity prices 1.5 x default values
Route type	Low efficiency	Low speed urban routes
	Baseline	Medium speed urban routes
	High efficiency	Commuter/suburban routes
Midlife costs	Baseline	Battery warranty covers bus operating life; no midlife diesel engine overhaul
	Battery replacement 10%	BEB battery replacement cost of 0.1 x BEB purchase price; midlife diesel engine overhaul cost of 0.1 x respective purchase price of diesel and HEB buses
	Battery replacement 20%	BEB battery replacement cost of 0.2 x BEB purchase price; midlife diesel engine overhaul cost of 0.1 x respective purchase price of diesel and HEB buses
	Battery replacement 40%	BEB battery replacement cost of 0.4 x BEB purchase price; midlife diesel engine overhaul cost of 0.1 x respective purchase price of diesel and HEB buses
Bus depreciation and resale value	Baseline	8% depreciation index
	Depreciation	15% depreciation index
	No resale	Resale value set to zero
Interest rate	Low BEB, HEB interest rate	Interest rates of 1.0% assumed for BEB and HEB, and of 7.6% for diesel and biodiesel buses
	Med. BEB, HEB interest rate	Interest rates of 4.6% assumed for BEB and HEB, and of 7.6% for diesel and biodiesel buses
	Baseline	Interest rate of 7.6% assumed for all bus types

Results of sensitivity analysis for the TCO of a Padron LE bus are summarized in Figure 5-6. Further details for each TCO modeling input variable considered in the sensitivity analysis are included below.

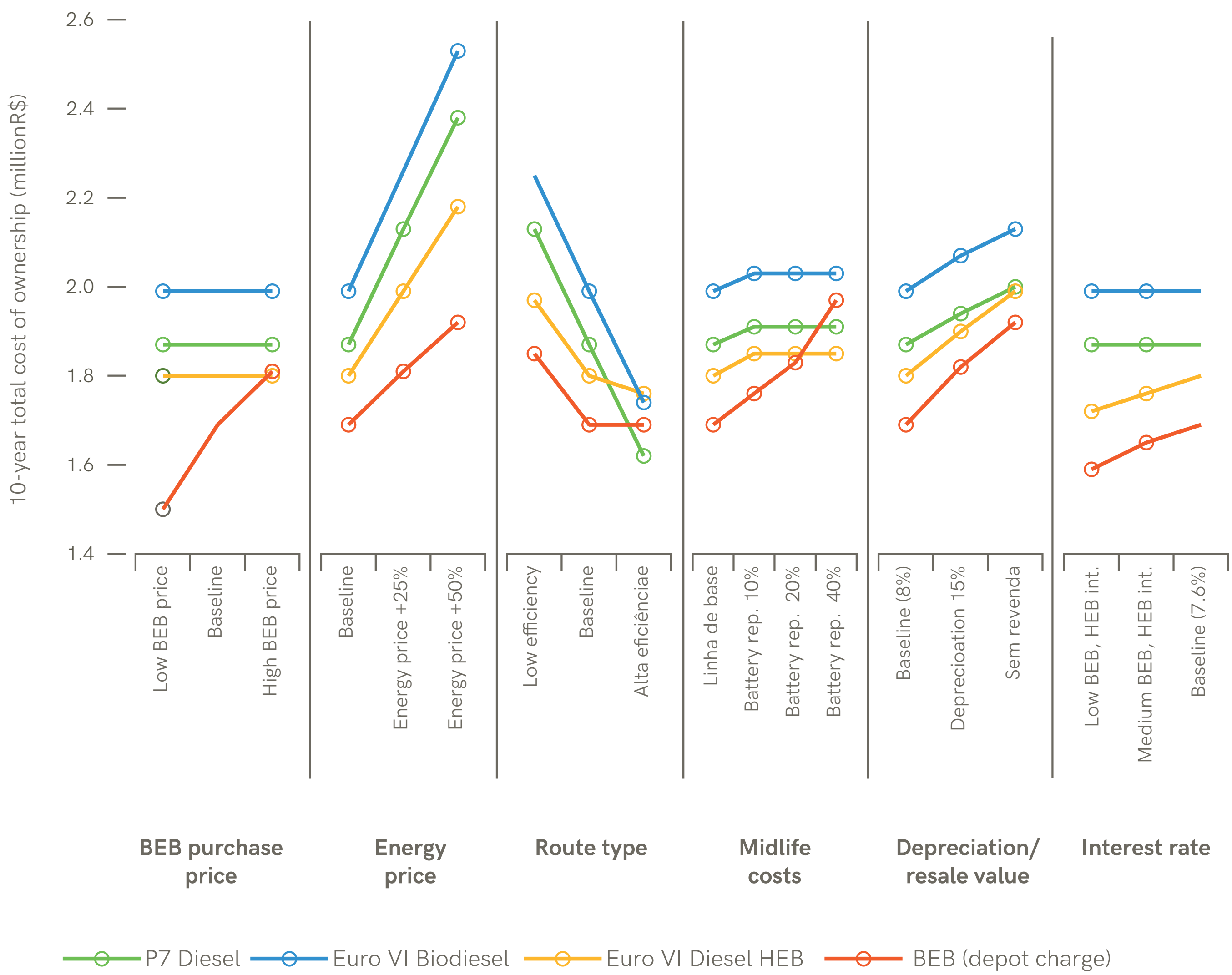

Figure 5-6 | **Sensitivity analysis for TCO of a Padron LE type bus**

BEB purchase price: a key barrier to transitions to battery electric bus technologies are the higher capital expenses for these technologies relative to conventional diesel buses. The base assessment assumes that the purchase price of a BEB was 1.75 greater than that for a P7 diesel bus. Increasing this ratio to 2, as was done in the high BEB sensitivity case, results in a 7% increase in the estimated TCO for the BEB bus. Even considering the higher purchase price, the TCO for the BEB in this case is still approximately 3% lower than the TCO for the diesel bus and about the same as the TCO for the diesel HEB. The low BEB price sensitivity case considers an incremental purchase price for the BEB of 1.3 relative to the diesel purchase price. This is reflective of projected purchase price reductions over the next 10 years in response to declining battery prices (CARB, 2017a). In this case, the TCO for the BEB is reduced by 11%, resulting in even greater life-cycle cost savings relative to other technologies.

Energy price: to explore the impact of assumed diesel and electricity prices on TCO estimates, two sensitivity cases are considered, in which these prices were increased by 25% and 50% relative to their baseline values. Of the four technology types, TCO estimates for the diesel and biodiesel buses were most sensitive to changing fuel prices. A 50% increase in the price of diesel or biodiesel fuel results in a 27% higher life-cycle cost for these technologies. By comparison, a similar increase in diesel fuel price increases life-cycle costs for the diesel HEB by 21%, while a 50% increase in the price of electricity increases the TCO for a BEB by only 14%. This dynamic reflects the fact that operational expenses account for a greater fraction of life-cycle costs for the diesel and biodiesel buses relative to electric drive technologies.

Route type: as noted above, the energy efficiency of transit buses varies by route type. The base assessment considers efficiency benefits of electric drive technologies based on duty cycles representative of medium speed urban operations. This sensitivity analysis considers route types where all bus types would be expected to have lower (low speed urban) or higher (commuter or suburban) energy efficiencies. Results show the TCO of the biodiesel and diesel buses to be most sensitive to assumptions made regarding route type, with a variation of 30%. The energy efficiency for electric drive technologies varies less by route type, and, consequently, TCO estimates for the diesel HEB and the BEB are also less variable. For commuter or surburban routes, where efficiency benefits of electric drive technologies are lowest, diesel buses are estimated to have the lowest TCO. This leads to an important insight: electric drive technologies should be preferentially deployed on those routes where efficiency benefits relative to diesel buses are greatest in order to maximize potential operational cost savings.

Midlife costs: a key uncertainty in assessments of the TCO for battery electric buses is the treatment of battery replacement costs in those cases where batteries are not expected to maintain their performance throughout the operational lifetime of the bus. These costs will depend on the bus ownership model and the extent to which battery replacement costs are covered by manufacturer's warranties. The base TCO assessment did not model midlife costs for diesel or electric drive technologies. Considered here are the impacts on life-cycle cost estimates of including diesel engine overhaul costs for the diesel, biodiesel, and hybrid buses and battery replacement costs for the BEB. For each sensitivity case, midlife costs for diesel engine overhaul are estimated as 10% of the vehicle purchase price for each technology (CARB, 2017a). For the BEB, one-time battery replacement costs vary from 10% to 40% of the BEB purchase price. The lower bound estimate, 10%, corresponds to relative battery replacement costs reported by Proterra (CARB, 2017a). For the Padron LE type bus, the upper bound estimate, 40%, is approximately equal to the incremental difference in the purchase price of the BEB relative to the conventional diesel bus, which reflects the contribution of battery costs to the BEB purchase price. When midlife costs are considered, the BEB maintains its life-cycle cost benefit relative to other technologies for those cases where one-time battery replacement costs are 10% or 20% of the BEB purchase price. The life-cycle cost of the BEB is estimated to be 3% greater than that of the diesel bus in the case where battery replacement costs are set to 40% of the BEB purchase price.

Depreciation and resale value: in the base assessment, bus resale value is treated as a positive cash flow and is estimated as the depreciated value of the vehicle at the end of its operational lifetime using an assumed 8% annual depreciation rate. Considered here are sensitivity cases where the depreciation rate is increased to 15%, and where resale value is omitted from the TCO calculation. In an absolute sense, higher depreciation rates will have the largest impact on life-cycle costs for those technologies with the highest bus acquisition capital expenses. Thus, TCO estimates for the BEB are most sensitive to assumptions made regarding depreciation rate and resale value. In the case where resale value is set to zero, the BEB is still estimated to have the lowest TCO, about 4% lower than life-cycle costs for the diesel bus and diesel HEB.

Interest rate: an interest rate of 7.6% was assumed for all bus technologies in the base assessment. As discussed in Chapter 2, there is the possibility that more favorable financing terms will be available for electric drive bus procurement in Brazil (BNDES, 2018). The sensitivity assessment considered the effect lower interest rates, 4.6% and 1.0%, have on the TCO estimates for battery electric and diesel hybrid-electric buses. Results, presented in Figure 5-6, show that lowering the interest rate to 4.6% reduces the TCO for BEB and HEBs by 2% relative to the case in which an interest rate of 7.6% is assumed. Further lowering the interest rate to 1%, the TCO estimates for the BEB and HEB are 6% and 4% lower, respectively, than TCO estimates for the base assessment case.

In addition to the sensitivity cases described above, the analysis considered the impact of extended ownership periods on life-cycle costs for BEBs. São Paulo currently maintains restrictions for the average age of the transit bus fleet and for the service lifetime of individual buses. Under these restrictions, the service lifetime for diesel buses in the São Paulo fleet is limited to ten years. The base TCO modeling assumed an equivalent 10-year service lifetime for BEBs. However, due to the considerable operational savings offered by BEBs, it makes sense to consider longer ownership periods for this technology. Figure 5-7 shows the effect of extending the service lifetime of BEBs to 12 or 15 years on life-cycle cost estimates. To compare TCO estimates for varying ownership periods, per kilometer life-cycle costs are reported. These results show per kilometer life-cycle costs for the BEB are reduced by 10% and 21% in the cases where service lifetime is extended to 12 and 15 years, respectively.

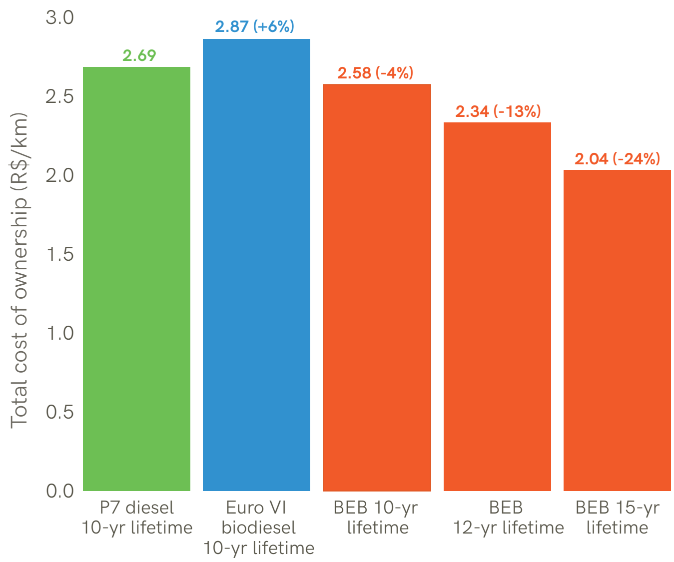

Figure 5-7 | **Sensitivity of TCO for a Padron LE BEB to bus ownership period** [46]

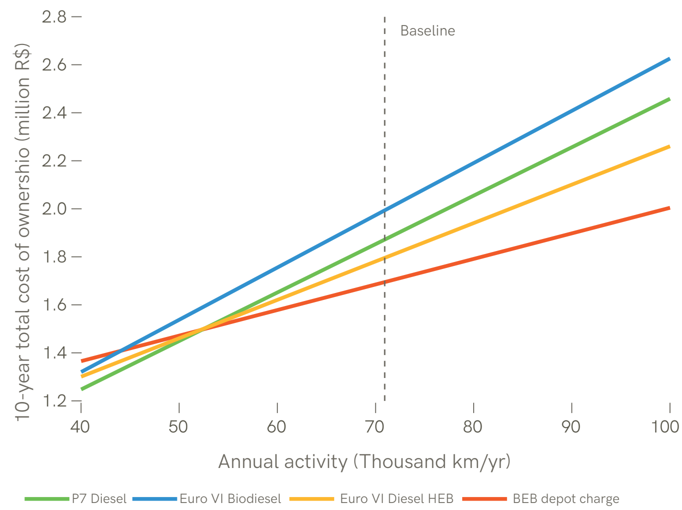

Figure 5-8 | **Sensitivity of TCO for a Padron LE type bus to annual activity**

Finally, the analysis considers the impact of assumed annual vehicle activity on TCO estimates. The base assessment applies one value for the estimated annual activity for each bus type, representing the average across all buses of a given type in the São Paulo fleet. In reality, there will be a range of annual activity for each bus type, depending on the routes and other operational considerations. Figure 5-8 shows the sensitivity of TCO estimates for a Padron LE type bus to annual vehicle kilometers traveled (vkt). In this case, annual vkt is varied from 40,000 to 100,000 km/year while all other TCO input variables are set to values used in the base assessment. For lower levels of annual activity (~40,000-50,000 km/yr), operational savings offered by electric drive technologies are not fully realized, and the diesel bus is estimated to have the lowest TCO of the four bus technologies. As annual activity increases, electric drive technologies become more competitive with diesel on a TCO basis, with the BEB estimated to have the lowest TCO when annual activity is 55,000 km/year or greater.

LIFE-CYCLE COSTS FOR FLEET REPLACEMENT

Single bus TCO results were applied to estimate the total costs of transitioning the entire São Paulo transit bus fleet to alternative bus technologies. The analysis considers the total lifetime costs of replacing the fleet with either biodiesel buses, depot charge BEBs, or diesel electric HEBs, and compares to a baseline scenario in which all new bus purchases are P7 diesels. The evaluation includes total costs of each bus technology for a 10-year procurement scenario, in which 10% of the fleet is replaced each year; and for a 5-year procurement scenario, in which 20% of the fleet is replaced each year. The 10-year replacement schedule approximates normal fleet replacement schedules, while the 5-year schedule is representative of an accelerated transition to electric drive bus technologies. The data presented in Table 5-2 are used to define fleet size by bus type and annual activity.

[46] Cost modeling inputs are set at baseline levels, with the exception of midlife costs. A diesel engine overhaul cost of 10% of the diesel bus purchase price is assumed for the diesel and biodiesel buses. A one-time battery replacement cost of 20% of the BEB purchase price is assumed for each BEB ownership period sensitivity case. Data labels show TCO for each technology and sensitivity case and the percent change in per kilometer TCO relative to the diesel baseline..

Cost estimates for each fleet replacement scenario are presented in Figure 5-9. These estimates represent the life-cycle costs of the replacement fleet in each procurement scenario following the same TCO methodology utilized for the single bus TCO assessment. A similar 10-year ownership period is assumed for each bus in the replacement fleet, and assumptions for other cost input variables are equivalent to those applied for the single bus base cost assessment. The net present value of life-cycle fleet replacement costs under the 10-year P7 diesel procurement scenario is estimated at R$18.2 billion. Results for diesel HEB and BEB procurement scenarios generally follow findings of the single bus TCO assessment, with estimated life-cycle cost savings of 3% and 8%, respectively, relative to the diesel procurement scenario. It should be noted that these results should be considered to be illustrative, at best. Uncertainties in modeling for the TCO of a single bus presented above are amplified when considering extrapolation to a 12,700 bus fleet.

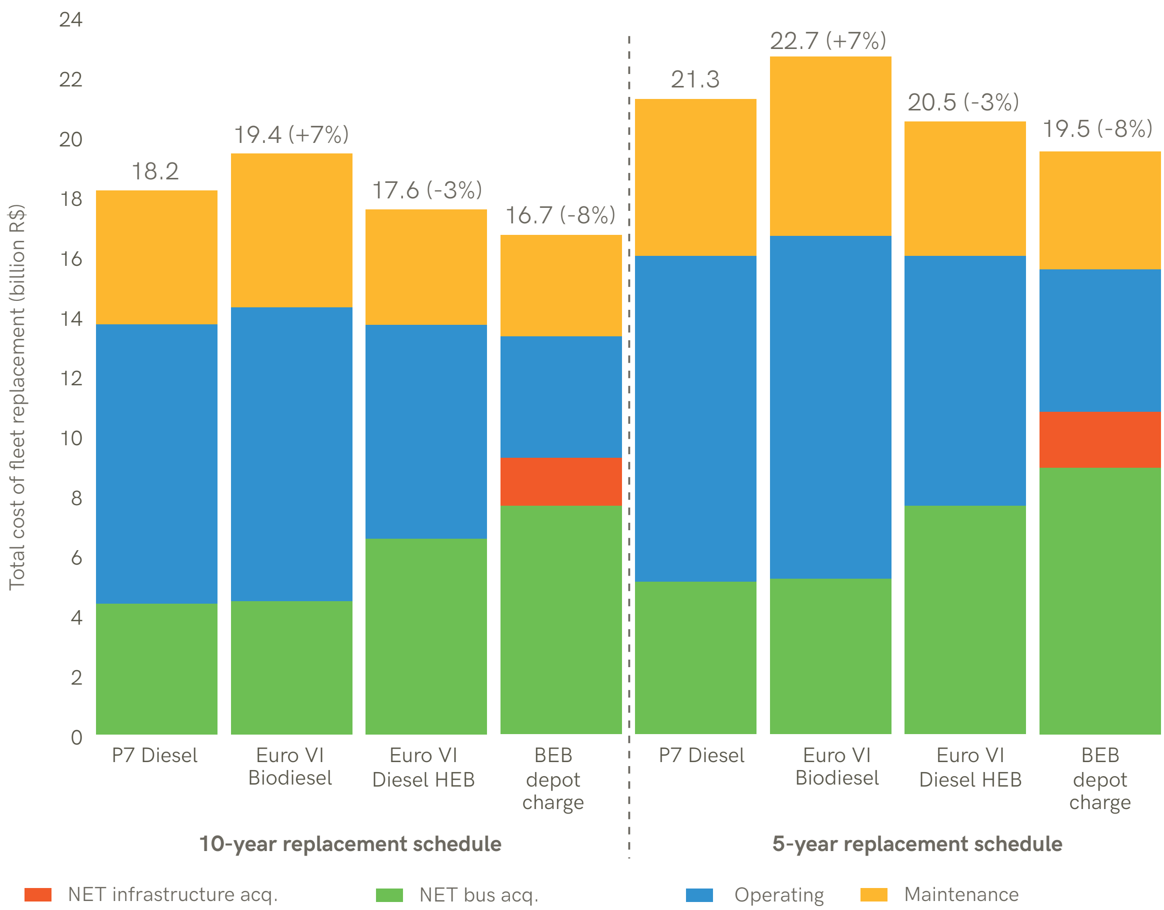

Figure 5-9 | **Total cost of São Paulo transit bus fleet replacement for diesel, diesel HEB, and depot charge BEB procurement scenarios under 10-year and 5-year replacement schedules**

CLIMATE EMISSIONS BENEFITS OF FLEET ELECTRIFICATION AND SOCIAL COST VALUATION

One of the primary drivers for electric drive bus transitions is the reduction in air and climate pollutant emissions. Given the low carbon intensity of the Brazilian electricity grid, transitions to battery electric buses, in particular, offer the potential for significant climate benefits. To evaluate the climate pollutant emissions benefits of electric drive bus transitions, the analysis estimated GHG and black carbon emissions for each of the three procurement scenarios considered in the fleet replacement cost assessment. Each scenario included tailpipe black carbon and WTW emissions emissions for the operating lifetime of the replacement fleet. GHG emissions include both direct and upstream emissions from fuel production and transport. The evaluation follows emission calculation methods developed in two recent studies of low-carbon urban bus fleets (Dallmann et al. 2017; Miller et al., 2017). Upstream emissions from biodiesel production include both direct emissions and emissions associated with changes in land use that result from increased biofuel production. Here, the analysis considers carbon intensity values of 28 gCO_2e/MJ for direct emissions (CARB, 2017c) and 150 gCO_2e/MJ for land use emissions (Valin et al., 2015) to estimate WTW emissions for buses using soy-based biodiesel fuel. For comparison, the WTW carbon intensity used in this anaylysis for petroleum diesel is 93 gCO_2e/MJ.

Results, presented in Figure 5-10, show cumulative climate pollutant emissions for each procurement scenario, expressed in units of million tonne CO_2e. These estimates reflect emissions for all buses in the replacement fleet over their 10-year service lifetimes. Relative to the baseline P7 diesel procurement scenario, climate emissions are reduced by 29% and 83% with fleetwide transitions to diesel HEBs and BEBs, respectively. In absolute terms, CO_2e emissions are reduced by 6.1 million tonnes in the diesel HEB procurement scenario and by 17.6 million tonnes in the BEB procurement scenario. For BEBs, climate benefits are representative of both the efficiency advantages of this technology relative to a diesel bus and the relatively low carbon intensity of the Brazilian electricity grid. No change in electricity generation mix with time is considered. Further decarbonization of the Brazilian grid would result in relatively better climate emissions performance for BEBs.

For the biodiesel bus procurement scenario, results show a substantial 57% increase in climate pollutant emissions relative to the P7 diesel procurement scenario. This result is attributable to the high land use emissions associated with soy-based biodiesel. Biodiesel produced from lower carbon intensity feedstocks could substantially reduce WTW climate pollutant emissions from biodiesel buses. These results show that the current generation of soy-based biodiesel fuels has significant climate emissions penalties relative to conventional petroleum diesel when life-cycle emissions, including those resulting from land use change, are considered.

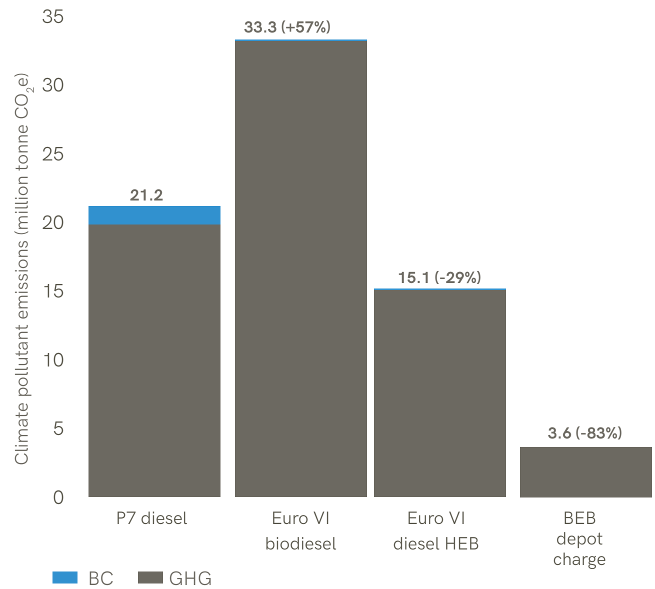

Figure 5-10 | **Lifetime climate pollutant emissions from the São Paulo municipal transit bus fleet under three fleet replacement procurement scenarios.**[47]

The cost components described thus far consider only the financial outlays associated with bus procurement and operation. The emissions of GHGs and black carbon from these buses incur costs borne by society that are not directly paid by the operator. Because investments in clean fuels and technologies can generate broader social benefit, the analysis also undertook an estimate of the additional climate and health damages of tailpipe black carbon emissions and fuel life-cycle GHG emissions from bus procurement.

The climate and health damages of GHG and black carbon emissions shown in Figure 5-10 were monetized using global average estimates for the social cost of atmospheric release (Shindell, 2013). The median values from that study, which are based on 2010 emissions levels and a 3% discount rate, are used here after adjusting for inflation. Although the precise value of climate and health damages varies according to time period and regional characteristics (e.g., geographic location, population size and density, and meteorological conditions), these values are useful as general indicators of the relative magnitude of climate and health benefits derived from investments in electric drive bus technologies. Monetized climate and health damages for the three procurement scenarios were added to the total cost of fleet replacement estimated for each scenario (Figure 5-9, 10-year replacement schedule). Results are shown in Figure 5-11.

[47] Assumes 100% fleet replacement with indicated technology type. Emissions represent WTW emissions throughout the 10-year ownership period of the replacement fleet. Black carbon emissions converted to CO_2 equivalent mass emissions (CO_2e) using a 20-year global-warming-potential value of 3200 (Myhre et al., 2013).

Considering social costs serves to further increase the estimated benefits of electric drive technologies relative to conventional diesel buses. For the baseline diesel procurement scenario, the social costs of pollutant emissions, primarily GHGs, are approximately 30% of the estimated direct costs for vehicle ownership and operation. The ratio of social costs to direct costs is reduced to 23% for the diesel HEB procurement scenario and to 6% for the BEB procurement scenario.

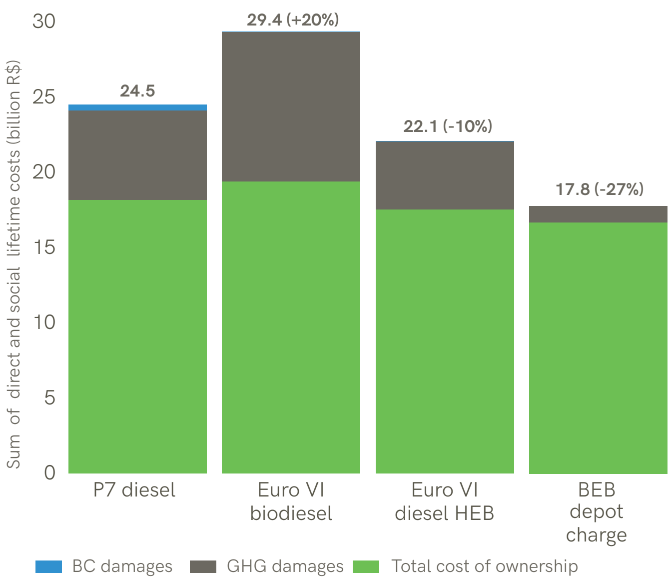

Figure 5-11 | **Total lifetime direct and social costs for the replacement of the São Paulo municipal transit bus fleet under three procurement scenarios**

SUMMARY

Electric drive transit bus technologies can offer considerable environmental and public health benefits relative to conventional diesel buses. With the continued development of these technologies, transit agencies and fleet operators are presented with an increasing number of options and opportunities for transitions to electric drive bus fleets. One of the most important considerations when evaluating the potential for such transitions is the cost of alternative technologies relative to conventional diesel buses. Electric drive technologies, such as diesel HEBs and BEBs, require greater capital expenditures for vehicle procurement, and, in the case of BEBs, charging infrastructure. However, over the lifetime of the bus these technologies also offer the potential for operational cost savings from, for example, reduced fueling and maintenance costs, which can make them competitive with conventional diesel buses. Thus, a key question for electric drive bus transitions is the degree to which operational savings offset the higher capital costs associated with these alternative technologies.

This chapter investigated this question through a TCO assessment of electric drive and conventional diesel bus technologies. The São Paulo municipal transit fleet was taken as a case study to explore the costs of electric drive bus transitions in Brazil. Using detailed operational and financial information for the São Paulo fleet, supplemented with data from international experiences with electric drive technologies, life-cycle costs for conventional and electric drive bus technologies were evaluated, including diesel HEBs, BEBs, and FCEBs, for each of the seven bus types used in São Paulo. A similar analysis was performed for biodiesel buses. Results from the single bus TCO assessment were then applied to estimate the total cost of replacing the entire São Paulo fleet with biodiesel buses, diesel HEBs or BEBs and compared to a business-as-usual scenario in which no changes are made to existing procurement practices. Lifetime fleet emissions of black carbon and GHGs were evaluated for each procurement scenario, as well as the monetized health and climate damages from these emissions. Finally, a sensitivity analysis was performed to explore the influence of individual cost components on TCO estimates and to account for uncertainty in underlying data and assumptions.

The base assessment found life-cycle costs for diesel HEB and BEB technologies to be competitive with those for P7 diesel buses for most of the bus types in the São Paulo fleet. For a Padron LE type bus, the analysis estimated lifetime cost savings of a diesel HEB relative to a P7 diesel bus to be 4%. The depot charge BEB was found to have the lowest TCO in the base assessment, with life-cycle costs estimated to be 9% lower than those for the conventional diesel bus. Due to greater infrastructure acquisition costs, the TCO estimated for an on-route charge BEB was higher, but still within 3% of the diesel bus TCO. The cost breakdown for the biodiesel bus was similar to that of the conventional diesel bus; however, relatively higher fueling and maintenance costs led to a slightly greater (+6%) TCO estimate. Relative rankings of technologies were generally consistent across bus types, with the exception of smaller buses, whose higher assumed per bus infrastructure costs pushed up the cost of BEB options relative to diesel buses and diesel HEBs.

The accuracy of these findings is contingent on the representativeness of values assumed for cost modeling input variables. The analysis attempted to address uncertainties in the selection of these values and to explore the impact of individual input variables on TCO estimates through a sensitivity analysis. For a diesel Padron LE type bus, life-cycle cost estimates were found to be most sensitive to modeling inputs related to the calculation of operating costs, such as the price of diesel fuel and assumed route type. In contrast, TCO estimates for a comparable BEB had a greater sensitivity to inputs related to capital expenditures, such as purchase price and midlife battery replacement costs. For many of the individual sensitivity cases considered here, the life-cycle costs for the BEB were competitive with those of the conventional diesel bus. Extended service lifetimes for BEBs should be considered in order to maximize operating cost savings offered by this technology.

The relative costs of replacing the São Paulo transit bus fleet with alternative bus technologies are consistent with single bus TCO estimates. Fleet replacement with diesel HEBs or BEBs, occurring over 5-year or 10-year timescales, offers costs savings relative to business-as-usual P7 diesel procurement scenarios. In contrast, transitions to a biodiesel bus fleet are estimated to be slightly more costly than conventional diesel bus procurement.

Transitions to electric drive bus technologies also offer the potential for significant reductions in climate pollutant emissions from the São Paulo transit bus fleet. Results indicate that replacing the São Paulo fleet with diesel HEBs would reduce emissions by approximately six million tonnes relative to a conventional diesel procurement scenario over the lifetime of the replacement fleet. A similar transition to BEBs would result in even larger climate pollutant emissions reductions – estimated here to be greater than 17 million tonnes. On the other hand, the analysis indicates that a transition to buses fueled with soy-based biodiesel could significantly increase WTW climate pollutant emissions from the São Paulo fleet. This finding is attributable to the relatively high land use emissions assumed in this analysis for soy-based biodiesel and indicates that lower carbon intensity feedstocks should be considered for any biodiesel bus procurement pathways.

6

CHALLENGES AND OPPORTUNITIES FOR ELECTROMOBILITY IN BRAZIL

Electromobility has been adopted as a solution for the mitigation of GHG and local air pollution, as well as for energy security in several countries. Brazil's first steps in this direction have been ad hoc, uncoordinated, and ultimately insufficient to advance electromobility.

A major challenge for electrification in Brazil is to go beyond current solutions for GHG mitigation and energy security, focused on biofuels, and advance toward complementary alternatives. Biofuels, a praiseworthy solution for Brazil considering its agricultural vocation, do not improve urban air quality, nor do they reduce long-term GHG emissions considering the projected fleet growth. In the case of biodiesel, the limitations are stronger due to its indirect land use changes, which can offset its climate benefits, and potential restrictions on production capacity. Along a pathway towards transportation decarbonization, vehicle electrification would complement biofuels, with added gains in energy efficiency that cannot be obtained with conventional technologies. The Brazilian electricity generation matrix, strongly based on renewable energy even in future projections, would leverage the benefits from electromobility.

The electrification of urban public transit is a priority in the short and medium term because it would bring together the benefits from electrification with investments in urban mobility. In addition to climate and air quality issues, urban mobility has brought to the forefront increasingly complex problems related to the uncontrolled growth of cities. Therefore, vehicle technology should not be dissociated from the main principles and guidelines to improve urban mobility, where public transportation shall be prioritized over individual motorized transportation, in accordance with the National Policy on Urban Mobility.

The comparative cost analyses of bus technologies presented in this study, with advantages for electric buses, reinforce the opportunities for electrification. As Brazil is already in a position to migrate to this niche more speedly, considering the cost and production capacity advantages, the efforts to overcome barriers would bring innumerable benefits. Expected gains include the reduction of GHG emissions and local pollutants, energy consumption, and operating and total costs, which may reduce tariffs, besides leveraging the nation's industrial competitiveness position for new technologies.

Therefore, the first challenge is to position vehicle electrification, particularly for public transportation, and to internalize it as a public policy, which would consequently lead to a natural coordination of efforts to accelerate its introduction. The various key actors would have a unique understanding and move in the same direction. The development of knowledge, now dispersed across research centers and universities, would be channeled into common work streams, thus improving final results. Additional investments would be made by the private sector based on firmer policy signals, scale gains would be achieved, and cost barriers would be reduced. The automotive industrial policy, currently under discussion, would clearly follow such policy signals, increasing the competitive advantages for Brazil vis-à-vis opportunities in international markets. Energy plans would incorporate consistent advances towards electrification. Additional efforts to improve electric bus technology and operations would intensify, with positive results. Following the example of São Paulo, other cities could adopt emission reduction targets for their public transportation service concession contracts, assured of the support they would have in terms of public policies and technological maturity – a natural consequence of such efforts.

The international experiences to stimulate electromobility have indicated a wide range of alternatives to be considered in the Brazilian context. Again, these experiences can serve as inspiration for actions to be taken once there is a clear policy path to follow. Subsequent steps will naturally arise from coordinated efforts, and mechanisms for monitoring and evaluation of results may require adjustments to the routes adopted as an evolutionary process of public policies.

ANNEX A. VALIDATION SEMINAR

CONTRIBUTIONS TO THE ISSUE OF ELECTROMOBILITY IN PUBLIC TRANSPORTATION

The study validation workshop, which took place on May 8, 2018 in Brasilia, was attended by specialists of various government agencies, academia and research organizations, the private sector, and non-profit organizations. The attendance list is included in Table A-2 in the end of this section.

This seminar was part of the technical cooperation project implemented by the Ministry of Industry, Foreign Trade and Services (MDIC) in partnership with the German Ministry for Economic Cooperation and Development, through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, called PROMOB-e (efficient propulsion systems).

As a result, in addition to bringing contributions to the study in question, specific topics were discussed in four groups formed with the participants. The issues presented to all of the groups were:

1. What are the three main challenges related to the adoption of electromobility in public bus transportation in a large Brazilian city?
2. Based on the international experiences summarized in Table A-1, please suggest at least one action or policy to overcome the challenges and accelerate the electrification of the bus fleet.
3. Detail the suggested actions or plans, including:
   - main agencies involved and their attributions;
   - key activities in the short, medium and long term;
   - necessary regulations;
   - expected results and gains.

Table A-1 | **Actions and policies for electromobility**

Category	Action
Clean vehicle and fuel regulations	• Clean vehicle mandates • Fuel efficiency standards • Clean fuel standards that credit electricity
Consumer incentives	• Vehicle purchase incentives (subsidies and tax exemptions) • Exemptions from annual fees • Preferential lane access • Preferential parking access • Discounted or free charging • Financing programs
Charging infrastructure	• Standard protocols for EVSE • EVSE incentives or funding • Direct deployment • EV-ready building codes
Planning, policy, and other promotions	• Procurement targets • Electric mobility strategy • Outreach and awareness • Demonstration projects • Fleet initiatives • Low-emission vehicle zones

For each group, an aspect was established to be further analyzed: recharge infrastructure; economic-financial balance of concession contracts; regulatory aspects of electric power; and vehicles and components – technological aspects and installed capacity. Different experiences were shared and contributions were generated, which are summarized below.

RECHARGE INFRASTRUCTURE AND REGULATORY ASPECTS OF ELECTRIC POWER

The major challenges identified regarding the recharge infrastructure and regulatory aspects of electric power refer to:

- Sizing and possible need for substations in the bus depots of public transportation providers. Along with this matter is the challenge of identifying who is responsible for such costs.
- Need for the standardization of vehicles and interfaces with the vehicle, for example. Unification of the recharging system was suggested.
- The regulatory issue, especially regarding electric power, and the definition of the business model associated with recharging.
- Technical and academic training, with challenges related to the technological development and to the need for technical competence in Brazil.
- The heterogeneity of the business models, which should, for example, fit the size of cities and the public transportation system.
- The discussion about differentiated rates for social purposes of public transportation. This rate would be aimed at recharging buses by the operators.

Some actions have been suggested to overcome the challenges presented:

- Carrying out pilot projects, allowing for assessment of solutions and operational impacts on a smaller scale. This would also enable technical training and technological maturity. For example, options for opportunity recharging (quick charging) or recharging in garages (slow charging) would be analyzed.
- Standardization (Inmetro/ABNT) so that there is a single recharging system.
- Creation of a fund with resources to incentivize the installation of EV recharging stations or recharging in garages.
- Vehicle labeling programs focusing on the energy efficiency of heavy-duty vehicles, creating a comparative standard that induces improvements through information.

The main agencies involved in the infrastructure are the government, industry, public transportation operators, and utilities companies. Regarding regulations, the government agencies involved are Ibama/Conama, Inmetro, Aneel, and ABNT.

ECONOMIC-FINANCIAL BALANCE OF CONCESSION CONTRACTS

The challenges that affect the economic and financial balance of concession contracts were:

- High cost of acquisition of electric and hybrid vehicles, in particular, of batteries, with still very low volumes, so that the local production thereof is feasible. High cost of super chargers as well.
- Unsustainability of the current model of remuneration adopted in many concessions. Accelerated depreciation, for example, and operating and maintenance costs, which are not always transparent or verifiable, are barriers to the introduction of new technologies.
- Volatility of foreign exchange rates, affecting the value of imports.

To address these issues, the following was suggested:

- Inclusion of battery, a major part of the total cost of the EVs, as a maintenance cost, equated with long-term leases (10 years, for example) or provision of service (from Capex to Opex).
- Longer depreciation for the EV. This modification is compatible with this technology, which is more durable. It is noteworthy that this can generate distortions in some situations, with concession contracts allowing an accelerated depreciation. This subject merits more in-depth study.
- The need to make incentive policy, such as financing at lower interest rates, compatible with the characteristics of the new technology, including grace periods and deadlines.

VEHICLES AND COMPONENTS: TECHNOLOGICAL ASPECTS AND INSTALLED CAPACITY

Lastly, contributions related to technology including vehicles and components were as follows:

- The challenges associated with EVs are related to the development of the entire production chain. Special attention to the battery, in the technological development process and with accelerated price reduction in recent years. Issues associated with their disposal are also an aspect to consider.
- Still regarding batteries, considering their cost, the challenges refer to new business models, such as leasing.

- Included in the technological challenges are the recharging stations, with emphasis on quick charge, plus the load capacity and impacts on the power grid.

As a way of overcoming the challenges regarding the technology, the following is proposed:

- Temporary and decreasing subsidies for the purchase of batteries.
- Development of the value chain for batteries (lithium ions), including electrolytes, cathodes, anodes, separators and other components.
- Financing and development.
- Tax policy as a stimulus to the new technology, including temporary exemptions and reductions from import tariffs for electric bus batteries.
- The adoption of technologies for integration with renewable sources.

The agencies that are expected to be involved with these proposals are MDIC, MME, BNDES, Ministry of Cities, the Office of the President of Brazil, and Aneel.

In conclusion, several groups have indicated the expected results of public health gains, GHG reductions, energy efficiency gains, positive impact on the trade balance, and greater industrial competitiveness.

Table A-2 | **Participants in the validation workshop**

Participant	Affiliation
Adalberto Maluf	ABVE/BYD
Alexandre Parker	Volvo
Allan Parente Vascncelos	DREnergy
André Tabuquini	MDIC
Amanda Souza	Promob-e
Berta Pinheiro	WRI
Bruno Carvalho	Promob-e
Carmen Araujo	ICCT
Ceres Barbosa	CGEE
Clarisse Cunha Linke	ITDP
Claudia Ramirez	SDG
Cristian Benito	MAN
Cristiano Façanha	ICCT
Dante Hollanda	MCTIC
Davi Martins	Greenpeace
Eduardo Soriano	MCTIC
Felipe Barcellos	IEMA
Fernando Araldi	MCID
Fernando Fontes	MDIC
Flavio Raposo de Almeida	EPE
Frank Peter Gundlach	MAN
Gustavo Victer	MDIC
Jairo Coura	MCTIC
Jens Giersdorf	Promob-e
José Luiz Rego Medeiros Cunha	SPTrans
Leonardo Boselli	MDIC
Luiz Carlos Almeida Junior	MDIC
Luiza Lima	Greenpeace
Marcos Costa	Promob-e
Marcus Regis	Promob-e
Marcio Massakiti	Itaipu
Raul Fernando Beck	CPqD
Ricardo Gonçalves Araujo Lima	DREnergy
Ricardo Guggisberg	ABVE
Ricardo Martins Araújo	ABDI
Ricardo Zomer	MDIC
Rudi van Els	UnB
Samy Kopit	ABDI
Simão Saura Neto	SPTrans
Tadeu de Melo	Petrobras
Tais Fonseca	SDG
Tatiana Bermudez	Unicamp/Leve
Thenartt Barros	MME
Thomas Caldellas	Mdic
Ubiratan Castellano	MME
Wagner Setti	WEG
Ricardo Takahira	Promob-e

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