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RESEARCH ARTICLE

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PROMOTING BUS ELECTRIFICATION THROUGH POLICY MECHANISMS: A CASE STUDY IN LARGE CITIES IN BRAZIL

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ABSTRACT

Ambient air pollution is one of the main global health risks, causing significant excess mortality and loss of life expectancy LLE, especially through cardiovascular diseases.Diesel burning produces air pollutants such as carbon monoxide (CO), NOx, benzene, sufur oxides (SO_x), 1,3-butadiene and primary particulate matter PM10. These pollutants increase the incidence of bronchitis, asthma, and pneumonia for at-risk populations, especially in large cities.The objective of this paper is to propose a new policy mechanisms approach to promote lithium battery buses in large cities in Brazil. Public health, together with global emissions, makes this substitution an important issue to be addressed by policymakers. This project showed that capital costs and infra-structure development, also techno-economic and market-control policies are the best options to promote electric battery and charging infrastructure development. Manaus was the only city that doesn't need policy incentives for the next life cycle to promote electric buses. Brasilia, Salvador and Fortaleza needed a useful life standard policy to become feasible. Furthermore, Sao Paulo, Rio de Janeiro and Belo Horizonte needed the useful life and State and Federal tax reduction as policy mechanism to become feasible.

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INTRODUCTION

Transport is the sector with the highest final energy consumption and, without any significant policy changes, is forecast to remain so (International Energy Agency [IEA], 2017a). Globally, in 2016 the transportation sector accounted for 30% of total final energy consumption, and the energy-related CO_2 emissions surpassed those from the electric power sector (United States Energy Information Administration [EIA], 2017). Furthermore, the transport sector accounts for 65% of final oil consumption, (IEA, 2018). Transport's share of global energy-related CO_2 emissions is 23%, increasing by 2.5% annually between 2010 and 2015 (IEA, 2017b). This trend must be reversed to get on track with 2DS targets. With the submission of NDCs to the Paris Agreement, a long-term political signal was sent to decarbonize the transport sector. A strong bias towards passenger transport is evident in the NDCs (Paris Process on Mobility and Climate [PPMC], 2016). Air pollution is a well-known burden for population health and health systems worldwide (Maesano *et al*., 2020). According to World Health Organization (2020), an estimated 4.2 million premature deaths globally are linked to ambient air pollution, mainly from heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infections in children. Ambient air pollution is one of the main global health risks, causing significant excess mortality and loss of life expectancy LLE, especially through cardiovascular diseases. It causes an LLE that rivals that of tobacco smoking. The global mean LLE from air pollution strongly exceeds that by violence (all forms together), i.e. by an order of magnitude (LLE being 2.9 and 0.3 years, respectively) (Lelieveld, J. *et al*., 2020). The main pollutant emissions produced by urban diesel vehicles are nitrogen oxides (NOx) and particulate matter (PM)(Mata, Gomez, & Armas, 2017). Diesel burning produces air pollutants such as carbon monoxide (CO), NOx, benzene, sufur oxides (SO_x), 1,3-butadiene and primary particulate matter PM10 (Chen, Namdeo & Bell, 2008). These pollutants increase the incidence of bronchitis, asthma, and pneumonia for at-risk populations (Beatty & Shimshack, 2011). Maesano *et al*. (2020) quantify health impacts of PM10 reduction in a single district of Paris, France, for various methods of traffic improvement. For the scenario requiring a completely electric passenger fleet, with long-term annual reductions of 137.14 premature mortalities per 100,000 people. Removing all diesel vehicles is the third most impactful scenario, preventing 135.55 deaths per 100,000 people yearly. Sarkodie *et al*. (2019) examined the approximate determinants of industrial PM2.5 emissions and the effect on life expectancy and mortality from 2000 to 2016 in Europe, Central Asia, Australia, Canada and the US. Ambient air pollution contributes significantly in reducing life expectancy and increasing mortality. An increase in industrial PM2.5 emissions per capita by 1% decreased life expectancy by 0.004% and mortality rate by 0.02% (95% CI).

Intensification of energy consumption and its related services by 1% were found to increase industrial PM2.5 emissions by 0.42–0.45% (95% CI) (Sarkodie *et al.*, 2019). According to Tong *et al.* (2020), total PM2.5 emissions were closely associated with road traffic conditions and largely determined the magnitude of the health impacts caused by traffic-related PM2.5 exposure in Beijing, China. PM2.5 concentrations have shown a sharply decreasing trend during the period from 2013 to 2017 in China (Lu *et al.*, 2019). The premature mortality associated with PM2.5 concentrations dropped from 1,078,800 in 2014 to 962,900 in 2017. Consequently, the health cost avoided in 2017 as a result of the reduction of PM2.5 concentrations amounted to 1.58% of the national GDP (Lu *et al.*, 2019). Together with electricity generation by renewables, electrification of high duty vehicles (HDV's) in cities could help countries to achieve the 2DS target. It would also help the mitigation of local emissions, which is usually a health problem in most of large cities. Governments can help to promote HDV's electrification through accelerating the deployment of these technologies by showing clear signs of their determination to invest in the required infrastructure, supporting demonstration programs, and vehicle efficiency regulations. The objective of this paperisto propose a new policy mechanisms approach to promote lithium battery buses in large cities in Brazil. The specific objectives to achieve this objective are:1. To estimate global and local emissions of diesel buses in large cities in Brazil;2. To conduct a techno-economic and market assessment of electric buses in Brazil; 3.To evaluate and classify the existing policy mechanisms in Brazil and the world related totransportation sector; and 4. To propose a new policy mechanisms approach to promote lithium battery buses in large cities in Brazil.

METHODOLOGY

In this project, the avoided emissions in the substitution of diesel buses by plug-in electric buses were analyzed in cities with the population over 2 million people in Brazil. This includes 7 cities and the federal district Brasilia (Instituto Brasileiro de Geografia e Estatística [IBGE], 2020). The methodology applied to estimate WTW global and local emission is the IPCC Guidelines for National Greenhouse Gas Inventories (Intergovernmental Panel on Climate Change [IPCC], 2006) and EMEI/CORINAIR Guideline for Emission Inventory (European Environmental Agency [EEA], 2016). Two approaches were applied to estimate global and local emissions of diesel urban buses (mobile and stationary): bottom-up and top-down. For NO_x, MP, CO, CH_4 and N_2O emissions, the bottom-up approach is applied considering activity data and emission factor according to the corresponding technology.For estimating CO_2, a top-down approach is used based on the fuel consumed by the analyzed object. The emission factor is related to the fuel type and not to the vehicle technology. Also, SO_2 emission is estimated using a top-down approach since the calculation is a function of the maximum sulfur content admitted by the fuel specification. The IPCC (2006) subdivides the calculations into different Tiers, i.e. distinct sets of equations that vary according to the availability of study data (input data) and the degree of detail of the method for estimating the total emission of each pollutant. Usually three tiers are provided. Tier 1 is the basic method, tier 2 intermediate and tier 3 the most demanding in terms of complexity and data requirements. Thus, the higher the tier, the greater the accuracy of the estimation. The tier choice should be based on the activity data available to the country (IPCC, 2006). In the present study, tier 2 is used to estimate emission of NOx, MP, CO, CH_4 and N_2O from mobile sources, considering the vehicle category and its emission pattern (EEA, 2016), as shown in equation 1.

$$Emission_x = \sum(d_{ij} * EF_{ij}) \quad \text{(Equation 1)}$$

Where:
$Emission_x$= Annual emission [g]
x = Pollutant type
d = Annual distance [km]
EF_{ij} = Emission factor [g/km]
i = Vehicle technology category
j = Fuel type

Tier 1 is used to estimate the emissions of NO_x, MP, CO, CH_4 and N_2O from stationary sources (EEA, 2016), as shown inequation 2.

$$Emission_x = \sum(A_{ki} * EF_{ki}) \quad \text{(Equation 2)}$$

Where:

$Emission_x$ = Annual emission [g]
x = Pollutant type
A = Annual activity data [kWh] or [kg] or [l]
EF = Emission factor [g/kWh] or [g/kg] or [g/l]
k = Process/stage
i = Type of energy source

Tier 1 is also used to estimate emission from CO_2 and SO_x from mobile and stationary sources (EEA, 2016), following equation 3.

$$Emission_x = \sum(c_i * EF_i) \quad \text{(equation 3)}$$

Where:
$Emission_x$ = Annual emission [g]
x = Pollutant type
c = Annual fuel consumed [km]
EF_{ij} = Emission factor [g/km]
i = fuel type

The GHG emission is expressed in CO_2eq. The CO_2-equivalent emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon (IPCC, 2018). The current study uses 100-year GWP values from the IPCC Fifth Assessment Report, consistent with current international and national GHG inventory practices. WTW electricity chain is divided into exploration, processing of primary energy and transportation for power plants (upstream process),electricity generation,transmission, distribution, charging of electricity and end use (Choi & Ho, 2018). Figure 1 illustrates the electricity WTW frame.

For diesel fuel, WTW analysis is divided into four steps: upstream processes which include oil extraction, processing and transport to oil refinery; oil refining, fuel distribution from refinery to retail centers, distribution in retail centers, and end use. Figure 2 illustrates the diesel WTW frame. For the diesel fleet, country-specific EFs (in g/km) was taken from the Environmental Protection Agency of São Paulo (Companhia Ambiental do Estado de São Paulo [CETESB], 2018) and used to estimate bus emissions(distribution and end use). Due to lack of national data, for the refining processthe data was taken from IPCC Emission Factor Database (IPCC, 2020). Upstream emissions were estimated according to the World Resource Institute (WRI, 2020).In Brazil, upstream emissions account for approximately 5,5% of fossil fuel lifecycle emissions (refining and end use). Operationalbus data was collected from the transportation agencies in each of the seven selected cities. Regarding the electric fleet, the annual average EFs (in g/kWh) of the national electricity matrix was used to estimate emissions from power generation, considering power grid (transmission and distribution) and charging dissipations [1]. The percentages of electricity loss in transmission and distribution grids were collected from the brazilian National Electric Energy Agency (Agência Nacional de Energia Elétrica [ANEEL],2019), whereas charginglosses were collected from United States of America National Renewable Energy Laboratory [NREL] (2018), as shown in Table 1.

[1]Greenhouse Gas Emission Estimative System (SEEG) methodology calculates the average generation emissions, considering all plants that are generating energy and not only those that are operating at the margin (SEEG, 2018). If all electricity consumers in the national interconnected system (SIN) calculated their emissions by multiplying the energy consumed by this emission factor, the sum would correspond to the emissions from the SIN (SEEG, 2018).

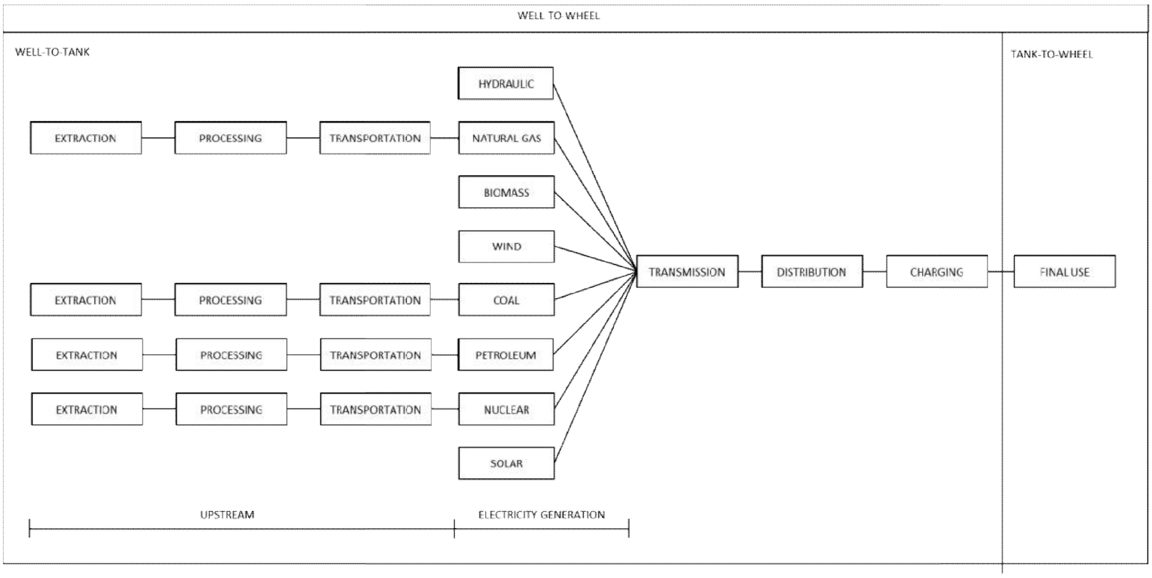


Figure 1. Electricity WTW Analysis

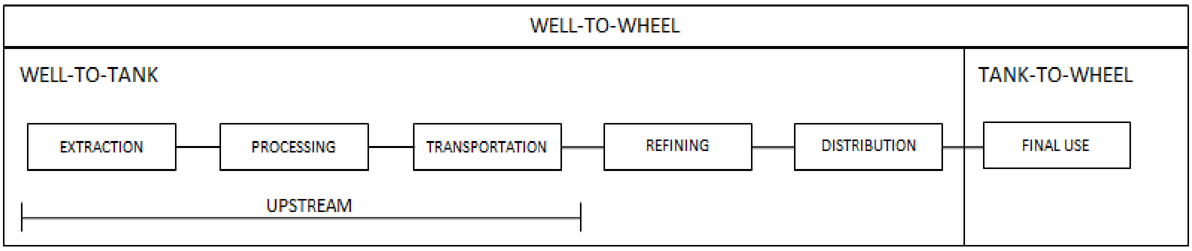


Figure 2. Diesel WTW Analysis

Table 1. Power energy dissipation in generation-charging stage

Stage	Dissipation	Reference
Transmission	4,0%	ANEEL, 2019
Distribution	13,5%	ANEEL, 2019
	8,0%	NREL, 2018

Source: Own elaboration based on ANEEL (2019) and NREL (2018).

Due to lack of national data to estimate MP and SO_X emission for each polluting electricity source of the Brazilian electricity matrix, international EF (in kg/GWh) was taken from EEA (2016) for natural gas, oil derivatives, coal and biomass. Renewable sources (except biomass) are considered zero emission in electricity production (Choi, Shin & Woo, 2018). Nuclear source (uranium) is also considered zero emission in this stage as it produces very low emissions (Choi, Shin & Woo, 2018) (Empresa de Pesquisa Energética [EPE], 2016). Operational bus data was collected from transport agencies in each 7 selected cities and the federal district.

For the financial analysis, fixed costs of buses werefoundfrom a survey in the Brazilian retail market. Financial feasibility comparison among diesel and lithium battery buses is done using theNet Present Value (NPV) and payback period methods, using the software Excel. Equation 4 illustrates the NPV method.

$$NPV\ (i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \qquad \text{(equation 4)}$$

Where,
t: time of the cash flow;
i: the discount rate;
R_t: the net cash flow.
Payback period, which is the length of time required to recover the cost of an investment, will be also estimated.

For diesel and electricity prices, this project considered the short data set available and used alinear equation to project them, considering the best-fitting straight line using the least square method. An estimation of lithium battery price in 2030 is made through the experience curve method, as described in IEA& Organization for Economic Co-operation and Development [OECD](2000). A trend line is a fit of a power function to the measured points in a log-log plot.Experience curves shows a relationship between price and the cumulative production or use of a technology. The curve is described by the mathematical expression in equation 6.

$$P_t = P_0 * X^{-E} \qquad \text{(equation 6)}$$

Where,
"P_t" is price at year t
"P_0" is a constant equal to the price at one unit of cumulative productionor sales.
"X" is cumulative production or sales inyear t.
"E" is theexperience parameter, which is the inclination of thecurve.

Large values of E indicate a steep curve with a high learning rate. Progress ratio (PR) is also used in experience curves to describe price reduction after a doubling of cumulative sale. The relation between the progress ratio, PR, and theexperience parameter is according to equation 7. If progress ratio is for example 80%, it means that each time that cumulative production double, price is 80% from the previous one.

$$PR = \frac{P0 * (2X)^{-E}}{P0 * (X)^{-E}} = 2^{-E} \quad \text{(equation 7)}$$

With the financial feasibility, it is possible to map the existing policy mechanisms and choose the appropriate mechanisms to promote lithium battery buses. Existing policy mechanisms in Brazil and worldwide to promote energy renewable technologies will be found in the literature. Some studies classify energy policy mechanisms as technology-push or demand-pull policies; others classify as market incentives or command-and-control. The classification of these mechanism in this project for the transportation sector will use the aggregation method developed by De Mello Santana (2017). This classification aggregates the existing classification of into four categories, using the four criteria of technology-push, demand-pull, market incentives and command-and-control. Figure 1 illustrates the four categories created. The first category is called technology-control, where policies are technology-push and command-and-control type because they have the potential to reduce private costs and are mandatory. The second is called market-control policy, where policies are demand-pull and command-and-control type because they have the potential to increase private profits and are mandatory. The third is called open market policies, where policies are demand-pull and market-incentive type because they have the potential to increase private profits and are not mandatory. The last category is called techno-economic, and they are technology-push and market-incentive because they have the potential to reduce private costs and are not mandatory.

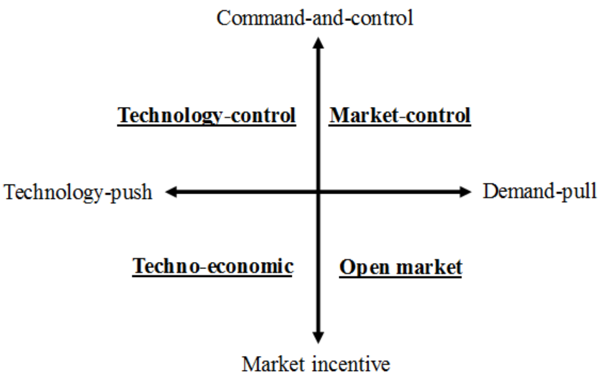


Figure 1. Classification of energy policy mechanisms

This classification aims to help policymakers better design and deploy energy policy mechanismsand will be used to classify existing transportation policies in the world and in Brazil. With the financial feasibilityand the policy mechanisms classified, it was possible to recommend the appropriate policy mechanisms to promote lithium battery for buses in federal, state and city level. The recommendation considers simulations in the financial feasibility and the likely impacts of the selected policy mechanisms. The energy classification and approach proposed in this project aim to help policymakers better design and deploy energy policy mechanisms in federal, state and city levels, to promote lithium battery buses in Brazil.

Global and local emissions of diesel buses in large cities in Brazil: This section estimates global and local emission abatement potential of substituting diesel buses by plug-in lithium battery electric buses in cities over 2.000.000 habitants in Brazil.As shown in table 1, seven cities account for approximately 15% of the total population in Brazil (IBGE, 2020). Table 2 demonstrates the public bus fleet and the distance travelled in 2018 for each selected city.There is a total of 34,467 buses in these cities, which traveled a total of 2,426,789,937 km. With the data in table 2 it is possible to estimate local and global emissions in all seven cities according to the WTW analysis. Table 3 illustrates the emissions results for all Diesel fleet in the selected cities. A total of 3.37 Mtons of CO_2eq was emitted in 2018 by the diesel fleet in all seven cities, also 6,172 tons of NOx, 201 tons of PM, 6,745 tons of SOx and 1,537 tons of CO.

Table 1. Estimated Population in Brazilian Municipalities (2019 reference)

State	City	Estimated Population	% of Total Population of Brazil
SP	São Paulo	12.252.023	6%
RJ	Rio de Janeiro	6.718.903	3%
DF	Brasília	3.015.268	1%
BA	Salvador	2.872.347	1%
CE	Fortaleza	2.669.342	1%
MG	Belo Horizonte	2.512.070	1%
AM	Manaus	2.182.763	1%

Source: IBGE (2019).

Table 2. Public Bus Fleet and Distance Travelled by selected city (2018)

State	City	Public Bus Fleet (number of buses)	Distance travelled in km (annual)[2]
SP	São Paulo	14,358	979,152,088
RJ	Rio de Janeiro	8,526	563,227,404
DF	Brasília	2,822	216,385,976
BA	Salvador	2,401	181,913,086
CE	Fortaleza	2,005	153,739,859
MG	Belo Horizonte	2,855	152,371,524
AM	Manaus	1,500	180,000,000

Source: SINETRAM (2020); Salvador Municipal Government (2020); Data Rio (2020); Mobility and Transport Department of São Paulo (2020); Collective Transport Society of Brasília (2020); Mobility and Transport Department of Fortaleza (2020).

Table 3. Diesel Fleet Emission (tons)

	NO_X	PM	SO_X	CO	CO_2eq
São Paulo	2,444	81	2,750	625	1,358,162
Rio de Janeiro	1,362	47	1,530	360	780,053
Brasília	623	18	602	121	299,010
Salvador	458	15	506	117	251,736
Fortaleza	446	13	432	99	223,845
Belo Horizonte	385	13	424	99	211,178
Manaus	453	15	501	116	248,848
Total	6,172	201	6,745	1,537	3,372,833

Table 4 shows the disaggregated diesel fleet emission in the upstream, refineries, distribution and end use. Considering the WTW results in the tables 3 and 5, it's possible to estimate the avoided emissions potential in the substitution of all diesel fleet by plug-in lithium battery fleet. Table 6 shows the avoided emissions potential in all seven cities, which represents a total reduction of 4.362 tons of NOx, 167 tons of PM, 6,202 tons of SO_X, 296 tons of CO and 3.05 Mtons of CO_2eq considering the substitution of all buses. This represents a reduction of 71%, 83%, 92%, 19%, and 90%, respectively, as shown in table 7. If it's considered a 10 years life cycle in average, emissions reduction would be around 43,620 tons of NOx, 1,67 tons of PM, 62,020 tons of SOx, 2,960 tons of CO and 3 Gtons of CO_2eq. The results in tables 6 and 7show the environmental benefits in the substitution of diesel buses by plug-in electric buses, reinforcing the public interest in this topic. Public health, already discussed in the introduction, together with global emissions, makes this substitutionan important issue to be addressed by policymakers. Next section evaluates the techno-economic assessment of electric buses in Brazil. This is necessary to verify the necessity to elaborate policy mechanisms to promote this substitution.

Techno-economic and market assessment of electric buses in Brazil: This section conducts a techno-economic analysis of electric buses in Brazil. Section 4.1 uses a trend scenario in all selected cities and section 4.2 creates a scenario for 2030 considering price decreasing of lithium battery package for the next bus life cycle, to prospect if a long-term policy would still be needed.

[2]Due lack of distance travelled data from Brasília and Fortaleza, this specific data was estimated by multiplying the number of buses to the average annual distance travelled per bus (76.678 km/bus) of the 5 other selected cities.

Table 4. Disaggregated diesel fleet emission (tons)

	NO_X	PM	SO_X	CO	CO_2eq	%
Upstream	318	10	351	80	174,885	5%
Refineries	891	138	5,572	158	951,220	28%
Distribution	69	1	6	10	18,219	1%
End use	4,893	52	817	1,290	2,228,509	66%
TOTAL	6,172	201	6,745	1,537	3,372,833	100%

Table 5. Electric Fleet Emission (ton)

	NO_X	PM	SO_X	CO	CO_2eq
São Paulo	751	14	334	515	133,171
Rio de Janeiro	432	8	69	296	76,603
Brasília	135	3	22	93	24,009
Salvador	140	2	62	96	24,741
Fortaleza	96	3	15	66	17,058
Belo Horizonte	117	3	19	80	20,724
Manaus	138	2	22	95	24,481
Total	1,809	34	543	1,241	320,787

Table 6. Avoided Emissionspotential (tons)

	NO_X	PM	SO_X	CO	CO_2eq
São Paulo	-1,693	-67	-2,415	-109	-1,224,991
Rio de Janeiro	-930	-39	-1,461	-64	-703,450
Brasília	-488	-15	-580	-28	-275,002
Salvador	-319	-13	-445	-22	-226,995
Fortaleza	-349	-10	-416	-33	-206,787
Belo Horizonte	-268	-10	-405	-18	-190,455
Manaus	-315	-13	-479	-21	-224,367
Total	-4,362	-167	-6,202	-296	-3,052,046

Table 7. Avoided Emissionspotencial (%)

	NO_X	PM	SO_X	CO	CO_2eq
São Paulo	-69%	-83%	-88%	-18%	-90%
Rio de Janeiro	-68%	-83%	-95%	-18%	-90%
Brasília	-78%	-86%	-96%	-23%	-92%
Salvador	-70%	-86%	-88%	-18%	-90%
Fortaleza	-78%	-80%	-96%	-34%	-92%
Belo Horizonte	-70%	-80%	-96%	-19%	-90%
Manaus	-70%	-88%	-96%	-18%	-90%
Total	-71%	-83%	-92%	-19%	-90%

Table 8. Life cycle for standard public bus fleet in the selected cities

	Useful life (years)
São Paulo	10
Rio de Janeiro	9
Brasília	10
Salvador	7
Fortaleza	10
Belo Horizonte	18
Manaus	10

Sources:Brazil House of Representatives (2015); São Paulo State Legislative Assembly (2015); Brazil Municipal Laws (2020a); Brazil Municipal Laws (2020b); Brazil Municipal Laws (2020c); Brazil Municipal Laws (2020d); Instituto Brasileiro de Defesa do Consumidor (2020); LegisWeb (2020).

Table 9. Annual maintenance difference estimation for 2019 in the seven selected cities

	Average distance per bus (km/year)	Annual Maintanence cost for diesel bus	Annual Maintanence cost for eletricbus ($)	Annual Maintanence difference ($)
São Paulo	68,200	$ 3,802.97	$ 2,535.32	$ 1,267.66
Rio de Janeiro	66,060	$ 3,683.64	$ 2,455.76	$ 1,227.88
Brasília	76,678	$ 4,275.74	$ 2,850.49	$ 1,425.25
Salvador	75,766	$ 4,224.84	$ 2,816.56	$ 1,408.28
Fortaleza	76,678	$ 4,275.74	$ 2,850.49	$ 1,425.25
Belo Horizonte	53,370	$ 2,976.03	$ 1,984.02	$ 992.01
Manaus	120,000	$ 6,691.45	$ 4,460.97	$ 2,230.48

Sources: SINETRAM (2020); Salvador Municipal Government (2020); Data Rio (2020); Mobility and Transport Department of São Paulo (2020); Collective Transport Society of Brasília (2020); Mobility and Transport Department of Fortaleza (2020).

Techno-economic analysis for the substitution of diesel for lithium battery electric buses in the seven selected cities: Consumption ratios of commercially available electric buses tend to be between 0.9 and 1.8 kWh/km in models currently available in the market (Grijalva & Martinez, 2019). The current model 200EV from the builder BYD, which has a factory in Brazil, was chosen for the analysis. It had a performance of 0.95kWh/km over a 12-month period (fleet average, without electric heating) in Europe (Dennis Alexander BYD, 2019). Average electricity price was taken in theBrazilian Electricity Regulatory Agency (ANEEL) yearly from 2010 until 2019 from each of the 7 cities; a linear regression then was made to project those prices. The life cycle of buses was collected, and the results from standard public fleet are described in Table 8. In this paper, the currency used to convert Brazilian real R$ to U.S. dollar $ was from 06/07/2020 reference, 1 USD = 5.38 BRL. Maintenance costs were considered as $/0.037 per km for BYD lithium battery bus and $/0.056 per km for diesel buses in Brazil (Greenpeace, Rede Nossa São Paulo, Minha Sampa, Move Cidade, Instituto Brasileiro de Defesa do Consumidor, & Cidade dos Sonhos, 2018).

Table 10. ICMS tax and electricity and average prices in 2019 for public transportation in the seven selected cities

	State taxes for diesel (ICMS) in %	State taxes for public transport diesel (ICMS) in %	Average Fuel price for public transport ($/l)	Average Electricity price for electric buses, including state taxes ICMS ($/kWh)
São Paulo	18%	12%	0.46	0.125
Rio de Janeiro	12%	0%	0.50	0.179
Brasília	15%	0%	0.48	0.126
Salvador	18%	12%	0.49	0.138
Fortaleza	18%	8%	0.50	0.134
Belo Horizonte	15%	4%	0.49	0.161
Manaus	18%	18%	0.56	0.154

Sources: Brazilian Federation of Fuel and Lubrificants Trade (2020); ANP (2020); ANEEL (2020).

Table 11. Total expenditure for diesel and electric buses in 2019 in the seven selected cities

		Diesel			Electricity		
City	Average distance per bus (km/year)	Average Consumption per bus (l)[1]	Fuel price ($/l)	Total expenditure ($)	Average Consumption per bus (kWh)[2]	Electricity price ($/l)	Total expenditure ($)
São Paulo	68,200	38,315	0.54	$20,866.51	64,790	0.125	$ 8,114.89
Rio de Janeiro	66,060	37,112	0.59	$21,807.49	62,757	0.179	$11,219.24
Brasília	76,678	43,078	0.59	$25,305.09	72,844	0.126	$ 9,189.01
Salvador	75,766	42,565	0.61	$25,950.36	71,977	0.138	$ 9,899.53
Fortaleza	76,678	43,078	0.62	$26,743.38	72,844	0.134	$ 9,783.37
Belo Horizonte	53,370	29,983	0.60	$17,945.32	50,702	0.161	$ 8,164.90
Manaus	120,000	67,416	0.69	$46,238.67	114,000	0.154	$ 17,579.29

(1): it considers the specific consumption of 1.78 km/l (average value in Sao Paulo) (Municipal Transportation Office of São Paulo, 2020).
(2): it considers the specific consumption of 0.95 kWh/km(Dennis Alexander BYD, 2019).

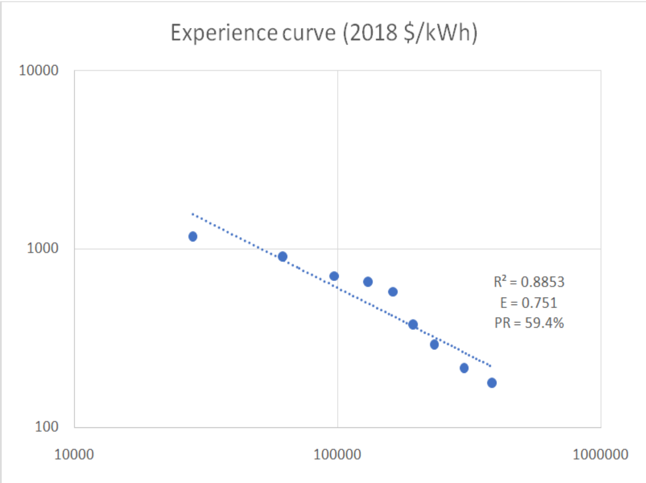
Table 12. Techno-economic assessment for the substitution of diesel for electric buses in the selected cities

City	IRR	NPV	Payback
São Paulo	-3.9%	$ -80,100	n
Rio de Janeiro	-8.0%	$ -104,902	n
Brasília	-0.4%	$ -48,239	N
Salvador	-8.5%	$ -91,195	N
Fortaleza	1.6%	$ -29,363	N
Belo Horizonte	-7.4%	$ -31,321	N
Manaus	9.5%	$ 62,192	6.5 years

It's reasonable that diesel maintenance prices are higher, because in diesel buses it's necessary to change oil periodically. Table 9 shows the annual maintenance difference estimation for 2019 in the seven selected cities. The values were used in the techno-economic analysis considering the life cycle of each city. Currently, there are subsidies as tax reduction for diesel used for public transportation in six out of seven States in which the cities belong. The state tax in Brazil is called ICMS, which lies on electric power and transportation services, among others.Table 10 shows the state taxes for diesel fuel and electricity in each of the seven selected cities, together with average prices of diesel and electricity in 2019. Table 11 shows the total expenditure for diesel and electric buses in 2019, multiplying the average distance of buses in the seven selected cities by their respective average prices. These numbers, together with price projections, is considered in the economic analysis. For the economic analysis, average price for diesel and electricity were projected using linear equations, which fit best the short time series available in the Brazilian National Petroleum Agency (Agência Nacional de Petróleo [ANP], 2020) and in ANEEL (2020) website. A research with retail market in Brazil was made to know the price of diesel and electric buses. In February/20 the average price found was $ 93,000.00 for each diesel bus and $ 316,000.00 for electric bus. BYD is the only manufacturer of electric buses in Brazil. From the $ 316,000.00, approximately $ 260,000.00 is the battery pack, representing 82,3% of total, according to BYD Brazil [Referência]. Table 12 illustrates the results of the economic analysis considering 4.25%of minimum attractiveness rate (Brazil long term Bond SELIC Feb/20 reference). São Paulo, Rio de Janeiro, Brasilia, Salvador, Fortaleza and Belo Horizonte have a negative NPV, indicating that the substitution of diesel by electric buses is not feasibly. The only city where it's feasible is Manaus, mainly due to the high average traveled distance per bus when compared with the other cities (see Table 10).

The payback period in Manaus is proximately 6.3 years, too long for Brazilian standards. The only two cities with a positive IRR were Fortaleza and Manaus, with 1.55% and 9.46% per year, respectively. However, the only feasible results would be in Manaus, since the minimum attractiveness rate considered was 4.25% per year. The short useful life of buses in each city is also one of the reasons for the non-feasibility in most cities.

Life cycle scenario considering price decreasing of lithium battery pack: This section creates a scenario for 2030 considering price decreasing of lithium battery package, to prospect if a long-term policy would still be needed. Electricity and diesel prices follow the same assumptions in section 4.1, which used linear equations to project prices.However, battery pack prices are falling rapidly year by year. Considering this rapid fall, it is necessary to project battery pack average prices to estimate electric bus prices in the future. For emerging energy technologies, experience curves are usually suitable to project these prices. Experience curves shows a relationship between price and the cumulative production or use of atechnology, as described in section 2. Figure 10 shows a trend line (fit of a power function) to the measured points in a log-log plot. R^2 foundin the power function was 88.5% and the experience parameter was 0.751, or 75.1%. The progress ratio (PR) of 2^{-E} was equal to PR=59.4%. It means that each time that cumulative production double, price is 59.4% of the previous one.



Source: Bloomberg NEF (2020).

Figure 10. Experience curve for lithium battery pack prices

Figure 11 shows the battery pack price projection through the experience curve method until 2030. Production estimation from 2019 until 2030 was taken from Statista dossier on lithium (Statista, 2020).

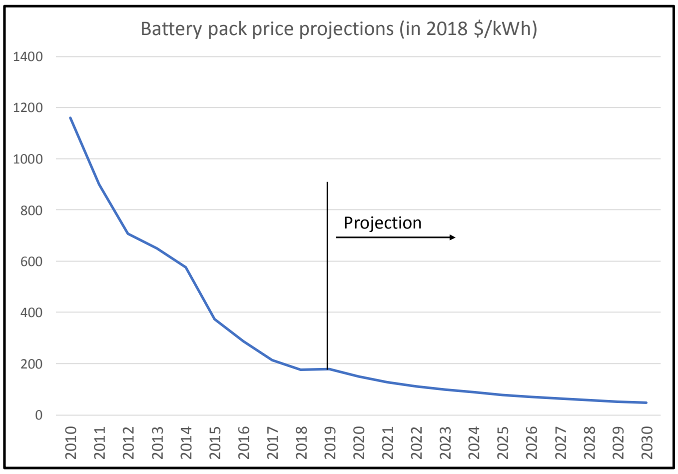


Figure 11. Battery pack price projection through the experience curve method

Considering price projection of the battery pack, is possible to estimate bus prices for the next life cycle of electric buses in the seven selected cities. As described before, from the BYD $ 316,000.00 electric busin 2020 in Brazil, approximately $ 260,000.00was the battery pack.

The percentual reduction found in the experience curve model is then applied in the $260,000.00 battery pack. Diesel bus is considered with the same price of $93,000.00a unit. Table 14 illustrates electric bus prices considering battery pack reduction according to the experience curve model.

Table 14. Electric bus price projection

	Expected battery pack price fall	Electric bus price estimations in Brazil
2020		$ 315,985.13
2021	-27%	$ 244,977.30
2022	-37%	$ 220,941.27
2023	-44%	$ 201,581.34
2024	-50%	$ 185,916.16
2025	-55%	$ 171,834.08
2026	-60%	$ 159,907.70
2027	-64%	$ 149,748.30
2028	-67%	$ 141,039.64
2029	-70%	$ 133,224.92
2030	-73%	$ 126,272.12

Price difference of diesel and electric bus in 2030 is projected to be $ 33.335.00 in 2030 due to battery pack reduction. With this price difference it's possible to calculate the economic feasibility. Interest rate is considered the same as section 4.1 (4.25% per year). Battery pack price reduction, together with projected diesel and electricity prices according to the same assumptions of section 4.1, leads to economic feasibility in all seven cities, with high IRR and NPV and low payback (0.7 to 2.2 years). Table 15 shows the results for the next life cycle in each of the seven cities, considering their useful life differences. It means that policy mechanisms are needed only for the next life cycle, since from 2030 electric buses would be feasible in the cities.

Table 15. Life cycle scenario considering price decreasing of lithium battery pack

Year	IRR	NPV	Payback
São Paulo	63%	$143,150.67	1.6 years
Rio de Janeiro	46%	103,141.56	2.1 years
Brasília	81%	$193,709.56	1.2 years
Salvador	44%	115,782.74	2.2 years
Fortaleza	93%	$232,544.35	1.1 years
Belo Horizonte*	62%	$247,724.61	1.6 years
Manaus	132%	337,345.41	0.7 years

*price in 2038 considered the same on 2030 because lithium battery production projection goes until 2030 only

Goldie-Scott (2019) also used the experience curve to estimate battery pack price fall up to 2030. The study considered other cumulative production input, and found that battery price pack will be around $94/kWh in 2024 and $62/kWh in 2030. All results are still techno-economically reasonable, including payback period.

Policy mechanisms in the world and Brazil for the promotion of transportation sector: Policy and incentives are responsible for cost reduction ofrenewable energy technologies. Policymakers have used variouspolicy mechanisms to promote clean energy technologies world wide in recent years, considering both technology-neutral and technology-specific approaches. Renewable port folio standards (RPS), feed-intariffs (FIT) and auctions are examples of recently used policy mechanisms that can have a technology-neutral or technology-specific approach, and policymakers usually seek cost- effective policy mechanisms to design and deploy these policies (De Mello Santana, 2016). Political support, operational data management, standardization, and demonstration projects are essential components that would move transit providers towards electric buses (Mohamed, Ferguson, & Kanaroglou, 2018). The main issues likely to impact the upscaling of electric bus use are related to the maturity, cost-effectiveness, compatibility, and charging efficiency of the available technologies (Xylia & Silveira, 2018). Risk mitigation, operational capabilities, and cost reductions are identified as significantly influencing the perspective of service providers and consequently the potential of the electric bus to penetrate the marketplace (Mohamed, Ferguson, & Kanaroglou, 2018). According to Li, Castellanos, & Maassen (2018), both public and private grants, when dedicated to cleaning the fleet, appear as a strong factor underpinning existing clean bus systems.

Public transport consumes 3.4 times less energy per passenger kilometer than automobiles (Carrilero et al., 2018). Furthermore, operation of electric lightweight buses enables energy savings of about 30% (Rogge, van der Hurk, Larsen, & Sauer, 2018). Some policymakers and researchers around the world are already promoting the electrification of buses. Gallet, Mmassier, & Hamacher (2018) shows that 50% of bus lines require less than 40 kWh per terminus-to-terminus journey in Singapore, which indicates a good potential for fast opportunity charging during layover time. Xylia, Leduc, Patrizio, Silveira, & Kraxner (2017a) optimized electric bus charger location in the city of Stockholm, also finds that the mean charging time is 7.33 minutes, with a standard deviation of 4.78 minutes for all bus stops in the city. Lower fuel costs for electric buses can balance the high investment costs incurred in building charging infrastructure, while achieving a reduction of up to 51% in emissions and up to 34% in energy use in the bus fleet (Xylia, Leduc, Patrizio, Kraxner, & Silveira, 2017b). Recent declines in Lithium battery prices are fully realized, the total cost of ownership of urban (intra-city) electric buses is lower than that for diesel buses in India even without agencies (Khandekar, Rajagopal, Abhyankar, Deorah, & Phadke, 2018).

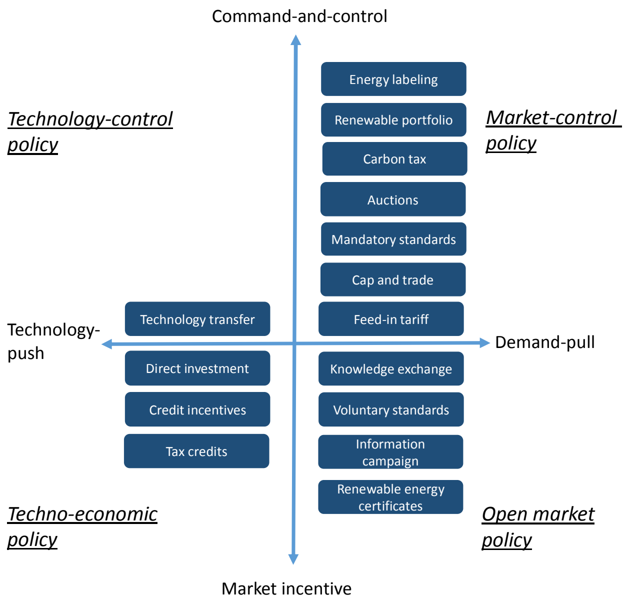


Figure 12. Classification of energy policy mechanisms

Furthermore, transitioning to an all-electric bus fleet presents an enormous opportunity for India to reduce urban air pollution while improving the finances of urban bus transit agencies (Khandekar, Rajagopal, Abhyankar, Deorah, & Phadke, 2018). The greater Sao Paulo Metropolitan area has a fleet of 350.000 HDV's (buses and trucks). This represents only 5% of total vehicles in the area, but it's responsible for 30% of carbon monoxide, 40% and 47% of benzene and black carbon atmospheric concentration, respectively (Brito et al, 2018). It represents an opportunity to evaluate the cost-benefits of lithium battery in HDV's, and how policymakers could help to promote the penetration of these technologies in large cities in Brazil. Under multiple incentive-based policies, the penetration of BEBs has increased rapidly to make China now rank first among the world's BEB markets (Du, Li, Li, Wu, Song , Zou, & Ouyang, 2019a).Du, Ouyang,Wu, Meng, Li, Li, Song, (2019b) investigated the influence of technological specification of Battery Electric Buses (BEB) in new subsidy scheme in China. The results show that normal-charging BEBs market for light-duty BEBs will shrink greatly due to significant reduction in the subsidy.However, the market penetration larger BEB will increase significantly. Furthermore, Lithium iron phosphate (LFP) batteries will dominate the normal-charging heavy-duty BEB market in short and medium term. However, Lithium Nickel Manganese Cobalt Oxide (NCM) batteries will dominate energy storage market for normal-charging BEBs due to its higher energy density. Li, Castellanos, & Maassen (2018) makes a comparative case study of electric buses implementation in 22 cities in 14 different countries. The study concludesthat public and private grants is a strong factor to promotebattery electric buses. Also,lower interest rate financing, which may come from different stakeholders, can reduce financial risks and leads to innovation.

Classification of energy policy mechanisms to promote battery electric buses in the world: This section classifies the energy policy mechanisms in 140 countries according to the IEA/IRENA Global Renewable Energy Policies and Measures Database, aggregating the existing classification of technology-push or demand-pull policies with market incentives or command-and-control, based on the 4QP method developed by De Mello Santana (2017). Figure 5 classifies some energy policy mechanisms into the 4QP category, using the four criteria of technology-push, demand-pull, market incentives and command-and-control. A total of 1,012 transport policies were deployedin 140 countries already according to IEA and International Renewable Energy Agency (IRENA) database (IEA & IRENA, 2020). From the 1,012 policies, 441 are exclusively or related to electric batteries. Table 16 shows the IEA/IRENA Global electric battery transport energy policies and measures by country. Table 17 shows IEA/IRENA Global electric battery transport energy policies by jurisdiction. It's possible to notice that national policies are the majority, with 75.5% of the total.

Table 16. IEA/IRENA Global electric battery transport energy policies and measures by country

Country	Policies
Canada	41
United Kingdom	27
People's Republic Of China	23
Netherlands	22
Spain	22
Portugal	21
Australia	18
France	17
Norway	17
European Union	15
Others	218

Table 17. IEA/IRENA Global electric battery transport energy policies by jurisdiction

Jurisdiction	Number
National	333
City/Municipal	53
State/Provincial	44
International	11

Table 18 shows the IEA/IRENA Global electric charging infrastructure policies and measures by country. A total of 277 policies were found; some of these policies are integrated with electric battery policies.

Table 18. IEA/IRENA Global charging infrastructure policies and measures by country

Country	Number of policies
Canada	15
European Union	14
Finland	11
Norway	10
United Kingdom	10
France	8
Netherlands	7
People's Republic Of China	7
Spain	6
Germany	5

Using the 4QP method, Figure 6 classifies the electric battery policy mechanisms into four categories, called 4QP method, developed by De Mello Santana (2017), which used the four criteria of technology-push, demand-pull, market incentives and command-and-control. The total surpasses 414 policies because some policy mechanisms have more than one approach.

Table 19. IEA/IRENA Global charging infrastructure policies and measures by jurisdiction

Jurisdiction	Number
National	90
City/Municipal (19)	19
State/Provincial (13)	13
International (10)	10

It's possible to notice in Figure 5, in the upper-right quadrant of Figure 2 shows the demand-pull and command-and-control category, called market-control policy. It was responsible for 279 (32% of the total) policies and measures in the 140 countries. The upper-left quadrant shows the technology-push and command-and-control category, called technology-control, with only 37 polices (4%). The lower-right quadrant shows the demand-pull and market incentive category, called open market policy, with 37 policies, which represents 4% of the total. The lower-left quadrant shows the technology-push and market incentive category, called techno-economic policy, with 510 policies and measures (59% of the total).

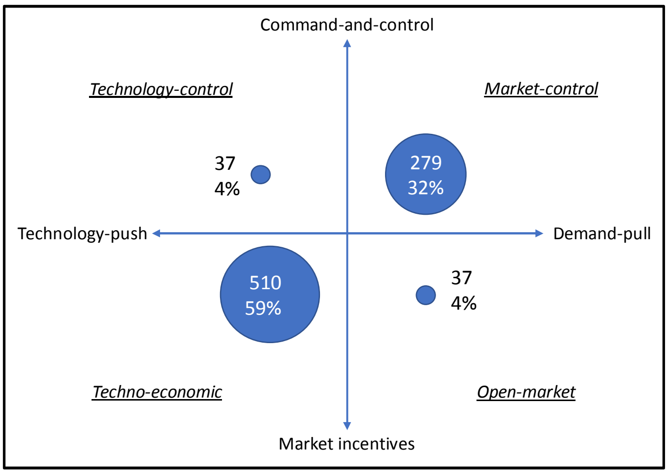


Figure 13. Classification of electric battery energy policy mechanisms

New approach for policy mechanisms to promotelithium battery buses in large cities in Brazil: It is possible to conclude from the previous sections that techno-economic and market-control policies are the best options to promote electric battery and charging infrastructure development. Techno-economic measures improve the economic feasibility of projects. According to BYD (electric bus factory in Brazil), the useful life of battery pack in buses ranges from 15 to 20 years. This means that 15 years is a reasonable useful life for electric buses. This would be the first techno-economic measure as a municipal policy measure since the cities defines it when they build bus bidding calls. According to the table 7, mostof selectedcities consider 10 years of useful life in the bus call, which includes São Paulo, Brasilia, Fortaleza and Manaus. Rio de Janeiro considers 9 years, Salvador only 7 and Belo Horizonte 18 years. The first proposal to improve techno-economic feasibility would be increase the useful life of São Paulo, Brasilia, Fortaleza, Rio de Janeiro and Salvador to 15 years. Manaus doesn't need support and Belo Horizonte already has 18 years of useful life in public bus calls. Simulating the techno-economic analysis of section 4.1 with the same premises, but with 15 years life cycle in São Paulo, Brasilia, Fortaleza, Rio de Janeiro and Salvador, the results show that three more cities become feasible. Brasilia, Salvador and Fortaleza are economically feasible with this change.

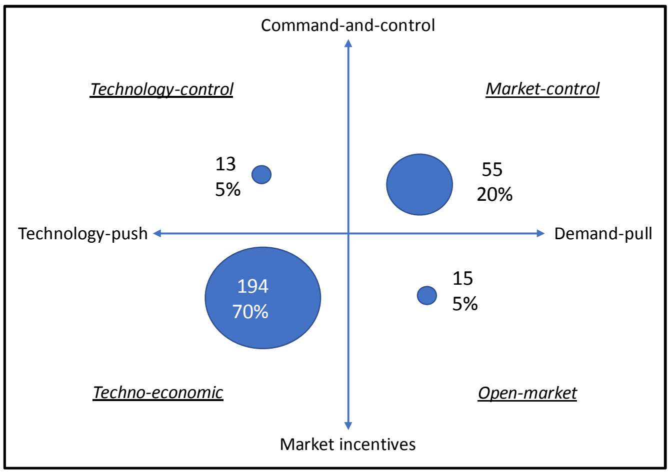


Figure 14. Classification of charging infrastructureenergy policy mechanisms

Table 20. No policy and policy economic analysis

	No policy			Useful-life reduction			Useful-life + State and Federal tax cut		
Year	IRR	NPV	Payback	IRR	NPV	Payback	IRR	NPV	Payback
São Paulo	-3.90%	$ -80,100	n	3.49%	$ -11,960.49	n	6.16%	$ 32,277.58	10.1 years
Rio de Janeiro	-8.00%	$-104,902	n	2.27%	$ -30,573.79	n	6.99%	$ 47,687.31	9.7 years
Brasília	-0.40%	$ -48,239	n	6.53%	$ 38,615.97	9.9 years			
Salvador	-8.50%	$ -91,195	n	7.34%	$ 53,322.86	9.5 years			
Fortaleza	1.60%	$ -29,363	n	8.31%	$ 71,960.37	10 years			
Belo Horizonte	-7.40%	$ -31,321	n	2.67%	$ -28,698.83	n	5.97%	$ 34,723.15	11.7 years
Manaus	9.50%	$ 62,192	6.5 years						

Figure 6 shows the classification of charging infrastructure policy.The upper-right quadrant of figure 6 shows market-control policy, with55 (20% of the total) policies and measures in the 140 countries. The upper-left quadrant shows the technology-control policies, with only 13 (5%). The lower-right quadrant shows the open market policies, with 15 policies, which represents 5% of the total. The lower-left quadrant shows the techno-economic policies, with 194 policies and measures (70% of the total). In both figures it's possible to notice that techno-economic policies tend to be the preferred policy measure. Electric batteries and charging infrastructure are capital intensive, so it's comprehensive that these policies are deployed by policymakers to promote private investments, decreasing somehow the capital costs. It would be also important to know the amount of money invested in each policy type; however, the database don't show this information.

São Paulo, Rio de Janeiro and Belo Horizonte are still not economically feasible, which means that they need also another policy mechanism.Another round of policy mechanismis conducted for these three cities, considering State and Federal tax cuts, an improvement of what happens already in Diesel buses in some States. Sao Paulo, Rio de Janeiro and Belo Horizonte would be benefited from these policy mechanisms, which would become feasible. Table 20 summarizes all results, considering a no policy scenario, useful-life and State and Federal tax cut.

Conclusion and Policy Implications: Ambient air pollution is one of the main global health risks, causing significant excess mortality and loss of life expectancy LLE, especially through cardiovascular diseases. The environmental benefits in the substitution of diesel buses by plug-in electric buses was shown in Brazil, reinforcing the public interest in this topic. Public health, together with global emissions, makes this substitution an important issue to be addressed by policymakers. Policy and incentives are responsible for cost reduction ofrenewable energy technologies. This project showed that capital costs and infra-structure development, also techno-economic and market-control policies are the best options to promote electric battery and charging infrastructure development. Manaus was the only city that doesn't need policy incentives for the next life cycle to promote electric buses. Brasilia, Salvador and Fortaleza needed a useful life standard policy to become feasible. Furthermore, Sao Paulo, Rio de Janeiro and Belo Horizonte needed the useful life and State and Federal tax reduction as policy mechanism to become feasible.

REFERENCES

Agência Nacional de Energia Elétrica (2019). *Perdas de Energia Elétrica*. Available: http://www.aneel.gov.br/metodologia-distribuicao/-/asset_publisher/e2INtBH4EC4e/content/perdas/654800?inheritRedirect=false. Access in 11 May 2019.

Agência Nacional de Energia Elétrica (2020). *Luz na Tarifa*. Available: https://www.aneel.gov.br/luz-na-tarifa. Accessed in 28 March 2020.

Agência Nacional de Petróleo (2020). *Série histórica do levantamento de preços e de margens de comercialização de combustíveis*. Available: http://www.anp.gov.br/precos-e-defesa-da-concorrencia/precos/levantamento-de-precos/serie-historica-do-levantamento-de-precos-e-de-margens-de-comercializacao-de-combustiveis. Accessed in 18 March 2020.

Beatty, T. K. M., Shimshack, J. P. (2011). School buses, diesel emissions, and respiratory health. *Journal of Health Economics*, v. 30, issue 5, p. 987-999. Available: https://doi.org/10.1016/j.jhealeco.2011.05.017.

Belo Horizonte Municipal Government (2020). Available: https://prefeitura.pbh.gov.br/sites/default/files/estrutura-de-governo/bhtrans/2019/documentos/Boletim%20TC%20JAN-2019%20(1).pdf. Access in 12 March 2020.

Bloomberg NEF (2020). Available: https://about.bnef.com/. Access in 25 February 2020.

Brazil House of Representatives (2015). *Viação e Transportes aprova vida útil de até 10 anos para ônibus interestaduais.* Available: https://www.camara.leg.br/noticias/454220-viacao-e-transportes-aprova-vida-util-de-ate-10-anos-para-onibus-interestaduais/. Access in 15 March 2020.

Brazil Municipal Laws (2020a). Available: https://leismunicipais.com.br/a/rj/r/rio-de-janeiro/resolucao-da-secretaria-municipal-de-transportes/2018/302/3013/resolucao-da-secretaria-municipal-de-transportes-n-3013-2018-define-conceitos-e-estabelece-a-idade-maxima-dos-veiculos-do-sistema-de-transporte-publico-por-onibus-sppo. Access in 15 March 2020.

Brazil Municipal Laws (2020b). Available: https://leismunicipais.com.br/a/ba/s/salvador/decreto/2008/1823/18226/decreto-n-18226-2008-aprova-o-regulamento-do-subsistema-de-transporte-especial-complementar-stec-do-municipio-de-salvador-2014-07-04-versao-compilada. Access in 15 March 2020.

Brazil Municipal Laws (2020c). Available: https://leismunicipais.com.br/a/ba/s/salvador/decreto/2008/1823/18226/decreto-n-18226-2008-aprova-o-regulamento-do-subsistema-de-transporte-especial-complementar-stec-do-municipio-de-salvador-2014-07-04-versao-compilada. Access in 15 March 2020.

Brazil Municipal Laws (2020d). Available: https://leismunicipais.com.br/a/am/m/manaus/lei-ordinaria/2013/177/1779/lei-ordinaria-n-1779-2013-dispoe-sobre-os-servicos-de-transporte-publico-coletivo-de-passageiros-no-municipio-de-manaus. Access in 15 March 2020.

Brazilian Federation of Fuel and Lubrificants Trade (2020). Available: http://www.fecombustiveis.org.br/wp-content/uploads/2020/01/Carga-tributária-estadual-Janeiro-2020-1ª-quinzena.pdf. Access in 28 March 2020.

Brito, J., Carbone, S., dos Santos, D. A. M., Dominutti, P., Alves, N. O., Rizzo, L. V., Artaxo, P. (2018). Disentangling vehicular emission impact on urban air pollution using ethanol as a tracer. *Scientific Reports*, v. 8, 10679. Available: https://doi.org/10.1038/s41598-018-29138-7.

Carrilero, I., Gonzalez, M., Ansean, D., Vieira, J., Chacon, J., Pereirinha, P. (2018). Redesigning European Public Transport: Impact of New Battery Technologies in the Design of Electric Bus Fleets. *Transportation Research Procedia*, v. 33, p. 195-202. Available: https://www.sciencedirect.com/science/article/pii/S2352146518302485.

Chen, H., Namdeo, A., Bell, M. (2008). Classification of road traffic and roadside pollution concentrations for assessment of personal exposure. *Environmental Modeling & Software*, v. 23, p. 282–287. Available: https://doi.org/10.1016/j.envsoft.2007.04.006.

Choi, H., Shin, J., Woo, J. (2018). Effect of electricity generation mix on battery electric vehicle adoption and its environmental impact. *Energy Policy,* 121, 13–24. Available: https://doi.org/10.1016/j.enpol.2018.06.013.

Choi, W., Ho, H. (2018). Well-to-wheel greenhouse gas emissions of battery electric vehicles in countries dependent on the import of fuels through maritime transportation: A South Korean case study. *Appl. Energy*, 230, 135–147. Available: https://doi.org/10.1016/j.apenergy.2018.08.092.

Collective Transport Society of Brasília (2020). Available: http://www.tcb.df.gov.br/. Access in 12 March 2020.

COMPANHIA AMBIENTAL DO ESTADO DE SÃO PAULO (2018). *Emissões Veiculares no Estado de São Paulo 2017*. Available: https://cetesb.sp.gov.br/veicular/wp-content/uploads/sites/6/2019/02/Relat%C3%B3rio-Emiss%C3%B5es-Veiculares-2017.pdf. Accessed in February 2020.

COMPANHIA AMBIENTAL DO ESTADO DE SÃO PAULO (2019). *Emissões Veiculares no Estado de São Paulo em 2018*. Available: https://cetesb.sp.gov.br/veicular/wp-content/uploads/sites/6/2019/12/Emiss%C3%B5es-Veiculares-no-Estado-de-S%C3%A3o-Paulo-Relat%C3%B3rio-2018.pdf. Access in 02 November 2019.

Data Rio (2020). Available: http://www.data.rio/datasets/total-de-linhas-frota-operante-passageiros-transportados-viagens-realizadas-quilometragem-coberta-combust%C3%ADvel-utilizado-e-pessoal-ocupado-pelo-sistema-de-%C3%B4nibus-no-munic%C3%ADpio-do-rio-de-janeiro-entre-1984-2018. Access in 12 March 2020.

De Mello Santana, PH (2016). Cost-effectiveness as energy policy mechanisms: The paradox of technology-neutral and technology-specific policies in the short and long term. *Renewable and Sustainable Energy Review*; Volume 58, p. 1216–22. Avaiable: https://doi.org/10.1016/j.rser.2015.12.300.

De Mello Santana, PH (2017). Energy for Regional Development. Jackson R., Schaeffer P. Reg. Research Frontiers, Vol. 1. Adv. Spat. Sci. (The Reg. Sci. Ser., Springer Cham; 2017, p. 151–60).

Dennis Alexander BYD (2019). *BYD and ADL leading the charge with pure electric vehicles*. Available: https://www.alexander-dennis.com/media/84563/byd-and-adl-leading-the-charge-may-2019.pdf. Access in February 2020.

Du, J., Li, F., Li, J., Wu, X., Song Z., Zou Y., Ouyang, M. (2019a). Evaluating the technological evolution of battery electric buses: China as a case. *Energy*, v. 176, p. 309–319. Available: https://doi.org/10.1016/j.energy.2019.03.084.

Du, J., Ouyang, M.,Wu, X., Meng, X., Li, J., Li F., Song, Z. (2019b). Technological direction prediction for battery electric bus under influence of China's new subsidy scheme. *Journal of Cleaner Production*, v. 222, p. 267-279. Available: https://doi.org/10.1016/j.jclepro.2019.02.249.

Empresa de Pesquisa Energética (2016). *Thermoelectric Energy: natural gas, biomass, coal, nuclear.*Available: http://www.epe.gov.br/sites-pt/publicacoes-dadosabertos/publicacoes/PublicacoesArquivos/publicacao-73/Energia%20Termel%C3%A9trica%20-%20Online%2013maio2016.pdf. Access in 29 September 2018.

Energy Information Administration (2017). Annual Energy Outlook 2017 with projections to 2050. Available: https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf. Access in 25 march 2019.

EUROPEAN ENVIRONMENTAL AGENCY [EEA], 2016. *EMEP/EEA Air Pollution Emissions Inventory Guidebook.* Available: https://www.eea.europa.eu/publications/emep-eea-guidebook-2016. Access in 28 October 2019.

Gallet, M.; Mmassier, T.; Hamacher, T. (2018). Estimation of the energy demand of electric buses based on real-world data for large-scale public transport networks. *Applied Energy*, v. 230, p. 344–356.

Goldie-Scott, L (2019). A Behind the Scenes Take on Lithium-ion Battery Prices. *Bloomberg, 2019.* Available: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/. Accessed in 19 March 2020.

Greenpeace, Rede Nossa São Paulo, Minha Sampa, Move Cidade, Instituto Brasileiro de Defesa do Consumidor, & Cidade dos Sonhos (2018). Combustíveis Limpos nos Ônibus da Cidade. Available: https://idec.org.br/sites/default/files/arquivos/cartilha_e_infografico_-_pl_da_poluicao_a4_1.pdf. Access in 19 March 2020.

Grijalva, E. R.; Martinez, J.M.L. (2019). Analysis of the Reduction of CO2 Emissions in Urban Environments by Replacing Conventional City Buses by Electric Bus Fleets: Spain Case Study. *Energies*, 12 (3), 525. Available: https://doi.org/10.3390/en12030525.

Instituto Brasileiro de Defesa do Consumidor (2020). Available: https://idec.org.br/sites/default/files/arquivos/cartilha_e_infografico_-_pl_da_poluicao_a4_1.pdf. Access in 15 March 2020.

Instituto Brasileiro de Geografia e Estatística (2019). *Estimativas da População Residente para os Municípios e para as Unidades da Federação Brasileiros com Data de Referência em 1º de Julho de 2019*. Available: https://agenciadenoticias.ibge.gov.br/media/com_mediaibge/arquivos/42ff76cf13a382a709c1ba14214b8612.pdf. Accessed in 29 November 2019.

Instituto Brasileiro de Geografia e Estatística (2020). Available: https://cidades.ibge.gov.br/brasil/panorama. Accessed in 10 February 2020.

Intergovernmental Panel on Climate Change (2006). 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html. Access in 03 July 2019.

Intergovernmental Panel on Climate Change (2018). *Climate Change 2014 Synthesis Report*. Available: https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf. Access in 14 December 2019.

Intergovernmental Panel on Climate Change (2020). *IPCC Emission Factor Database*. Available: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php. Access in 04 January 2020.

International Energy Agency & International Renewable Energy Agency (2020). *Policies Database*. Available: https://www.iea.org/policies. Access in 21 February 2020.

International Energy Agency (2017a). *World Energy Outlook 2017*. Available: https://www.iea.org/reports/world-energy-outlook-2017.

International Energy Agency (2017b). *Tracking Clean Energy Progress 2017: Energy Technology Perspectives.*OECD/IEA: Paris, 2017.

International Energy Agency (2018). *Key World Energy Statistics*. OECD/IEA: Paris, 2018.

International Energy Agency; Organization for Economic Co-operation and Development (2000). *Experience Curves for Energy Technology Policy*. Paris, France. 2000.

LegisWeb (2020). Available: https://www.legisweb.com.br/legislacao/?id=279154. Access in 15 March 2020.

Lelieveld, J., Pozzer, A., Pöschl U., Fnais, M., Haines, A., Münzel, T (2020). Loss of life expectancy from air pollution compared to other risk factors: a worldwide perspective. *Cardiovascular Research*, v. 116, Issue 7, p. 1334. Available: https://doi.org/10.1093/cvr/cvaa025.

Li, X., Castellanos, S., Maassen, A. (2018).Emerging trends and innovations for electric bus adoption—a comparative case study of contracting and financing of 22 cities in the Americas, Asia-Pacific, and Europe. *Research in Transportation Economics*. In press, Available: https://doi.org/10.1016/j.retrec.2018.06.016.

Lu, X., Lin, C., Li, W., Chen, Y., Huang, Y., Fung, J., Lau, A. (2019). Analysis of the adverse health effects of PM2.5 from 2001 to 2017 in China and the role of urbanization in aggravating the health burden. *Science of the Total Environment*, Volume 652, p. 683-695. Available: https://doi.org/10.1016/j.scitotenv.2018.10.140.

Maesano, C.N., Morel, G., Matynia, A., Ratsombath, N., Bonnety, J., Legros, G., da Costa, P., Prud'homme, J., Annesi-Maesano, I. (2020). Impacts on human mortality due to reductions in PM10 concentrations through different traffic scenarios in Paris, France. *Science of The Total Environment*, Volume 698. Available: https://doi.org/10.1016/j.scitotenv.2019.134257.

Mata, C., Gomez, A., Armas, O. (2017). The influence of ethanol-diesel blend on pollutant emissions from different bus fleets under acceleration transitions. *Fuel*, v. 209, p. 322-328. Available: https://doi.org/10.1016/j.fuel.2017.08.018.

Mobility and Transport Department of Fortaleza (2020). Available: https://mobilidade.fortaleza.ce.gov.br/. Access in 12 March 2020.

Mobility and Transport Department of São Paulo (2020). Available: https://www.prefeitura.sp.gov.br/cidade/secretarias/transportes/institucional/sptrans/acesso_a_informacao/index.php.Access in 12 March 2020.

Mohamed, M., Ferguson, M., Kanaroglou (2018). What hinders adoption of the electric bus in Canadian transit? Perspectives of transit providers. *Transportation Research Part D: Transport and Environment*, v. 64, p. 134-149. Available: https://doi.org/10.1016/j.trd.2017.09.019.

Municipal Transportation Office of São Paulo (2020). Available: https://www.prefeitura.sp.gov.br/cidade/secretarias/transportes/institucional/sptrans/acesso_a_informacao/index.php. Access in 20 February 2020.

National Renewable Energy Laboratory (2018). *Zero-Emission Bus Evaluation Results: County Connection Battery Electric Buses*. Available: https://www.nrel.gov/docs/fy19osti/72864.pdf. Access in 08 February 2019.

Paris Process on Mobility and Climate (2016). *Transport and climate change: Synthesis of analytical products by the Paris Process on Mobility and Climate.* Report for the 22nd Conference of the Parties: Marrakech.

Rogge, M., van der Hurk, E., Larsen, A., Sauer, D. (2018). Electric bus fleet size and mix problem with optimization of charging infrastructure. *Applied Energy*, v. 211, p. 282–295. Available: https://doi.org/10.1016/j.apenergy.2017.11.051.

Salvador Municipal Government (2020). Anuário de Transportes Urbanos 2018. Available: http://mobilidade.salvador.ba.gov.br/images/anuario/2018/ANUARIO_2018_Corrigido.pdf. Access in 12 March 2020.

São Paulo State Legislative Assembly (2015). Available: https://www.al.sp.gov.br/repositorio/legislacao/lei/2015/lei-15831-15.06.2015.html. Access in 15 March 2020.

Sarkodie, S., Strezov, V., Jiang, Y., Evans, T. (2019). Proximate determinants of particulate matter ($PM_{2.5}$) emission, mortality and life expectancy in Europe, Central Asia, Australia, Canada and the US. *Science of The Total Environment*, Volume 683, 489-497. Available: https://doi.org/10.1016/j.scitotenv.2019.05.278.

SEEG, 2018. *Metodologia*. Available: http://monitoreletrico.seeg.eco.br/pages/methodology. Access in 01 March 2019.

SINETRAM, 2020. Available: http://www.sinetram.com.br/. Access in 12 March 2020.

Statista (2020). *Lithium Statista Dossier*. Available: https://www.statista.com/study/40094/lithium-statista-dossier/. Access in 20 February 2020.

Tong, R., Liu, J., Wang, W., Fang, Y.(2020). Health effects of $PM_{2.5}$ emissions from on-road vehicles during weekdays and weekends in Beijing, China. *Atmospheric Environment*, Volume 223. Available: https://doi.org/10.1016/j.atmosenv.2019.117258.

World Health Organization, 2020. *Ambient air pollution: Health impacts*. Available: https://www.who.int/airpollution/ambient/health-impacts/en/. Access in 23 January 2020.

World Resource Institution [WRI], 2020. Available:https://wriorg.s3.amazonaws.com/s3fs-public/Fossil_Fuels_map-05.png. Access in 12 January 2020.

Xylia, M., Silveira, S. (2018). The role of charging technologies in upscaling the use of electric buses in public transport: Experiences from demonstration projects. *Transportation Research Part A: Policy and Practice*, v. 118, p. 399-415. Available: https://doi.org/10.1016/j.tra.2018.09.011.

Xylia, M.; Leduc, S.; Patrizio, P.; Kraxner, F.; Silveira, S. (2017b). Locating charging infrastructure for electric buses in Stockholm. *Transportation Research Part C: Emerging Technologies*, v. 78, p. 183-200. Available: https://doi.org/10.1016/j.trc.2017.03.005.

Xylia, M.; Leduc, S.; Patrizio, P.; Silveira, S.; Kraxner, F. (2017a). Developing a dynamic optimization model for electric bus charging infrastructure. *Transportation Research Procedia*, v. 27, p. 776-783.

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