Climate and Air Quality Scenarios for E-Bus Deployment:

Deep Dive City São Paulo, Brazil

City Characteristics

With a GDP of about U$ 147 billion in 2017, São Paulo is positioned as the richest city in Brazil[1]. São Paulo's economic, financial, and cultural influence goes beyond the regional and national scope. The city is the centre of the Metropolitan Region of Sao Paulo (MRSP), which comprises 38 municipalities and has a total population of 21.4 million people, about half the population of the state of São Paulo[2]. The city has an area of 1,521.11 km^2, and an estimated population of 12.39 million people in 2022, resulting in an urban density of about 7,400 inhabitants per km^2 (in 2021)[3].

São Paulo has significant social inequality. In 2017, the average monthly remuneration of workers was 4.2 minimum wage, while the population of 31.6% of households had an income of up to half a minimum wage per person[4]. The Gini coefficient, which measures inequality in income distribution on a scale of 0 to 1 (0 means a fully equal situation and 1 the opposite), was 0.53 in 2019. São Paulo's accelerated urban expansion and the lack of integrated urban planning have resulted in a growing process of spatial segregation and social inequality[5].

Transport system

São Paulo is the main transport hub in Brazil and South America. It has 3 airports, 3 bus terminals, 10 access roads and several local transportation options, such as trains, subways, taxis, rental vehicles and cycle routes.

In recent years, there is still a very intensive use of individual transport. According to data from the Mobility Survey 2021, approximately 44% of motorized trips were made by private modes and the remaining 56% by collective public transport.

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[1] IBGE, 'Sao Paulo'.

[2] IBGE.

[3] TUMI E-Bus Mission, 'Factsheet - Sao Paulo'.

[4] IBGE, 'Sao Paulo'.

[5] Nobre et al., 'Vulnerability of Brazilian Megacities to Climate Change: The São Paulo Metropolitan Region (RMSP)'.

In 2022, the city's total vehicle fleet was 8.9 million units of which more than 7 million are cars and pickup trucks, and 1.3 million are motorcycles or scooters. About 8.3 million vehicles are for individual motorised transport.

Before the Covid-19 pandemic, the modal split in São Paulo showed a prevalence of public transportation, with 37% of the daily trips, and a small but growing share of cycling, especially in areas with better infrastructure. There are 663.1 km of bike lanes and cycle tracks, and 2,700 bicycles for sharing, some of them already equipped with electric motors. The City's Bicycle Paths Plan pursues the goal of implementing 1,800 km of bicycle paths by 2028, including bridges, footbridges, and other works. Regarding shared bicycles, the goal is to serve 60% of the territory by 2024 and the entire territory of the municipality by 2028.

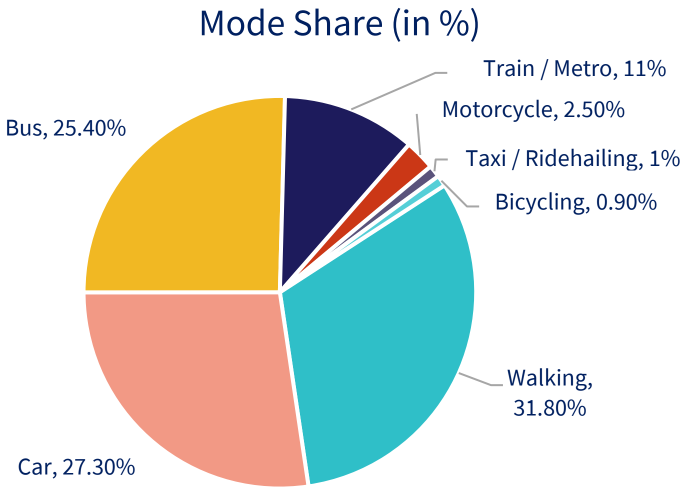

Figure 1: Modal Split of São Paulo. (Source: TUMI E-Bus Mission, 2022)

The bus network consists of 1.337 routes and 13.981 buses. It serves an average of 10 million passengers per day. São Paulo has 130 km of BRT corridors and a bus network of 4,500 km, with approximately 87% on roads where the space is shared with other modes. In these sections, buses are often stuck in traffic and lose speed, resulting in low reliability and reducing the attractiveness of public transport. PlanmobSP foresees the creation of a 1,460 km network of roads with exclusive lanes or corridors for public transport by 2032 (compared to 680 km today).

The subway has proven increasingly essential to connect different regions. In all, 104 kilometres house six lines, in addition to 280 kilometres of train tracks. The city has 13 urban rail and metro lines which have expanded at a rate of 1.2 stations per year. Work on two monorail lines has been chronically delayed.

Climate and air pollution targets

Transportation is the sector responsible for the largest share of total emissions, with values that have changed little over the years. The existence of large distances between neighbourhoods and the concentration of job opportunities in the central and southwestern regions of the city are factors that contribute to the intensive use of individual motorized transportation. The country's new PROCONVE P-8 emission standards (equivalent to Euro VI) came into effect in 2019 and applied to all new heavy passenger and freight vehicles.

The target set for GHG reduction in São Paulo's Climate Change Policy are:

- Unconditional target: By 2030, the City of São Paulo will reduce its greenhouse gas emissions by 20% compared to the base year of 2017.
- Conditional target: By 2030, the City of São Paulo will reduce its greenhouse gas emissions by 50% compared to the base year of 2017 if adequate actions are taken at the national level.
- Conditional target: By 2050, the City of São Paulo will reduce its net greenhouse gas emissions to zero if adequate actions are taken at the national level.

The Urban Mobility Plan of São Paulo (PlanMob), prepared in 2015, prioritises sustainable modes of transport, improvement of accessibility and safety of the mobility system and democratization of road space[6].

Targets and policies related to the procurement of e-buses

Among other mobility-related priorities, the Climate Action Plan mentions a move to electrify 100% of the municipal fleet by 2040 and to replace the municipal bus fleet with zero-emission vehicles[7]. São Paulo committed to a long-term target of introducing 13,979 electric buses by 2038 and a short-term target of 2,600 electric buses by 2024.

São Paulo's public transportation concessionaires have already ordered 2,152 new 100% electric buses. In 2023, 1,484 new electric buses will start operations, and another 668 are planned for 2024. Currently, 219 electric buses (201 trolleybuses and 18 battery-powered) are operating in the city.

The e-Bus Emissions Assessment Tool (eBEAT)

The eBEAT tool is co-developed by TUMI E-Bus Mission and SOLUTIONSplus. It is a bus stock model that integrates the evolution of the bus fleet based on the number of new entrants, considering sizes (for e-buses), fuel split and emission standards, a vehicle survival curve, new vehicle technology improvements, and vehicle degradation. The tool aims at a better understanding of the impact of an accelerated procurement of e-buses in cities in Asia, Africa, and Latin America.

The tool can calculate time-series estimations of emissions based on existing plans and targets for e-bus procurement and on 'what-if' scenarios that consider external factors such as changes in the national energy mix or transmission losses in the electricity grid. The

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[6] Prefeitura do Município de São Paulo, 'Plano de Ação Climática Do Município de São Paulo 2020-2050'.

[7] Prefeitura do Município de São Paulo.

calculator goes beyond greenhouse gas emissions and captures air pollutants and energy consumption.

While the calculator uses city-specific data on procurement plans and targets or vehicle-km, it also provides default values to reduce data requirements. Users can adapt default values for the e-bus and the 'what-if' scenario.

Impact of accelerated e-bus procurement on emissions

High-capacity, efficient, clean, and high-service-quality passenger transport modes such as electric buses (e-buses) play a critical role in accelerating the reduction of emissions from urban transportation.

To analyse the impacts of the accelerated e-bus procurement, we have developed two scenarios, viz., a base scenario and an enhanced scenario. The parameters that are used in each scenario are summarized in the table below:

Parameters	Base Scenario		Enhanced Scenario	
	2030	2050	2030	2050
Fleet Stock	10.270	150	10.270	18.150
T&D Losses	18%	18%	16%	9%
% of Renewable Energy	85%	85%	85%	85%

In the **base scenario**, we have considered both short-term and long-term targets set by the city up to 2050. The data was obtained from the TUMI e-bus network website and updated figures from the TUMI partners. For Brazil, we have estimated that 85% of the electricity is generated from renewable sources and the T&D losses will remain at 18% up to 2050.

In the **enhanced scenario**, a key assumption was that the entire bus fleet is electrified by 2050 unless the city defined an earlier target for full electrification, which is the case in São Paulo. We estimated the fleet up to 2050 based on the population growth in the city. We assumed the fleet availability per 1000 inhabitants would remain unchanged until 2050. This will lead to a fleet size of 18.150 vehicles in 2050, this would mean that the city needs to procure 43.970 e-buses until 2050, considering the vehicle retirement up to 2050. For Brazil, we have assumed that the share of electricity generated from renewable sources will increase to 85%, and the T&D losses will be halved to 9% up to 2050.

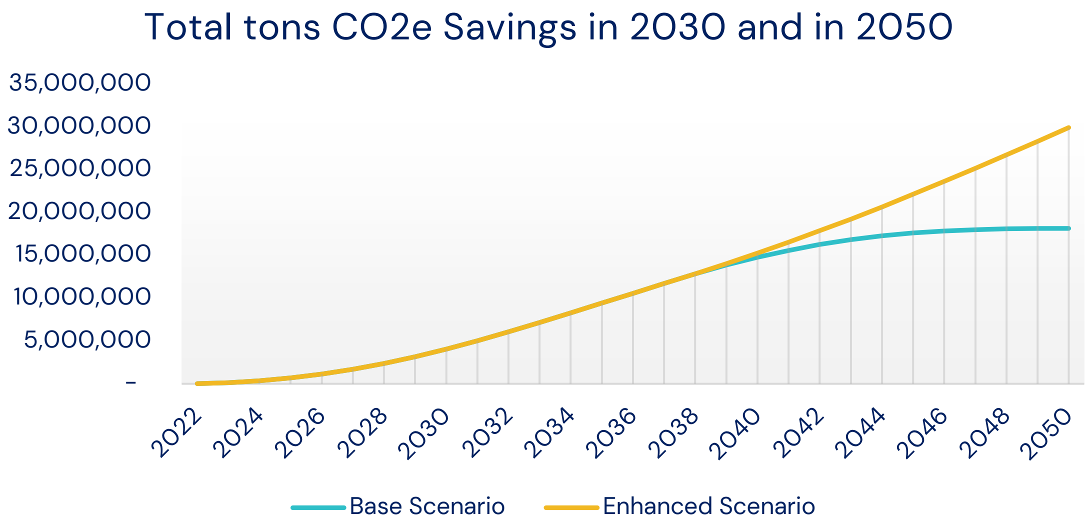
The tool estimates the cumulative savings for emissions and energy consumption by shifting to e-bus. Conventional urban buses are predominantly fuelled by diesel engines, emitting black carbon (BC), a harmful and carcinogenic particle. Other emissions that are analysed are the most crucial air pollutants source that significantly affects human health and environmental quality, such as NO_x and particulate matter (PM). The following table gives a snapshot of the cumulative savings from shifting to e-buses according to the base and enhanced scenarios:

Category (unit)	Base Scenario		Enhanced Scenario	
	Up to 2030	*Up to 2050*	*Up to 2030*	*Up to 2050*
BC (tons)	41	131	41	215
CH_4 (tons)	143	638	143	1.052
CO (tons)	1.197	4.555	1.198	7.356
CO_2 (kilo tons)	4.046	18.125	4.049	29.962
CO_2e (kilo tons)	4.051	18.147	4.054	29.999
N_2O (tons)	27	120	27	199
NMVOC (tons)	143	619	143	1.032
NO_x (tons)	2.387	7.736	2.394	12.320
PM_{10} (tons)	438	1.933	439	3.215
$PM2_{.5}$ (tons)	223	968	224	1.618
SO_x (tons)	-2	-5	-2	-2
TSP (tons)	661	2.931	662	4.873
Energy consumption (MWh)	6.310.000	29.010.000	6.400.000	51.250.000
Energy consumption (TOE)	540.000	2.490.000	550.000	4.410.000

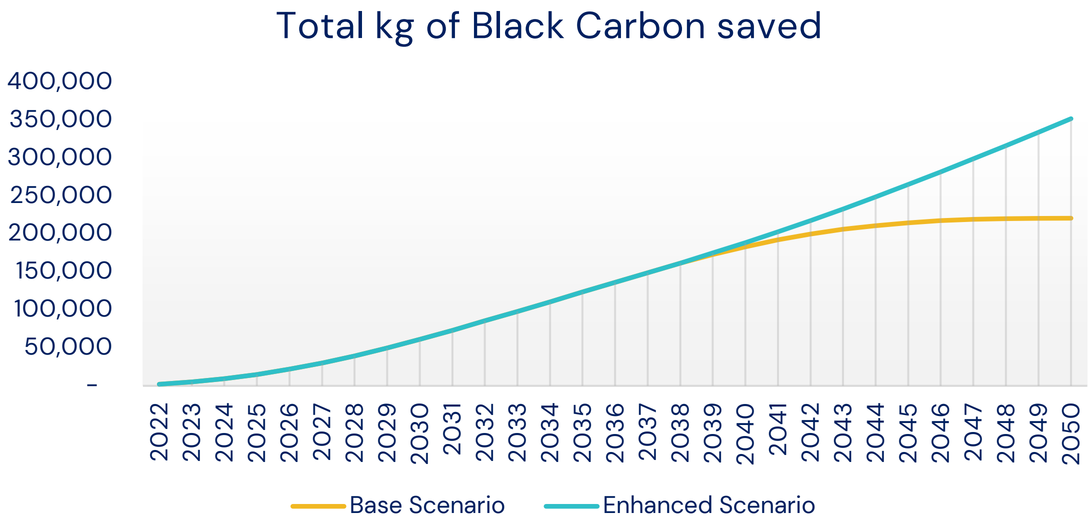
As São Paulo has set a target for full electrification of the bus fleet by 2038, the emission savings from the enhanced scenario are apparent from 2039.

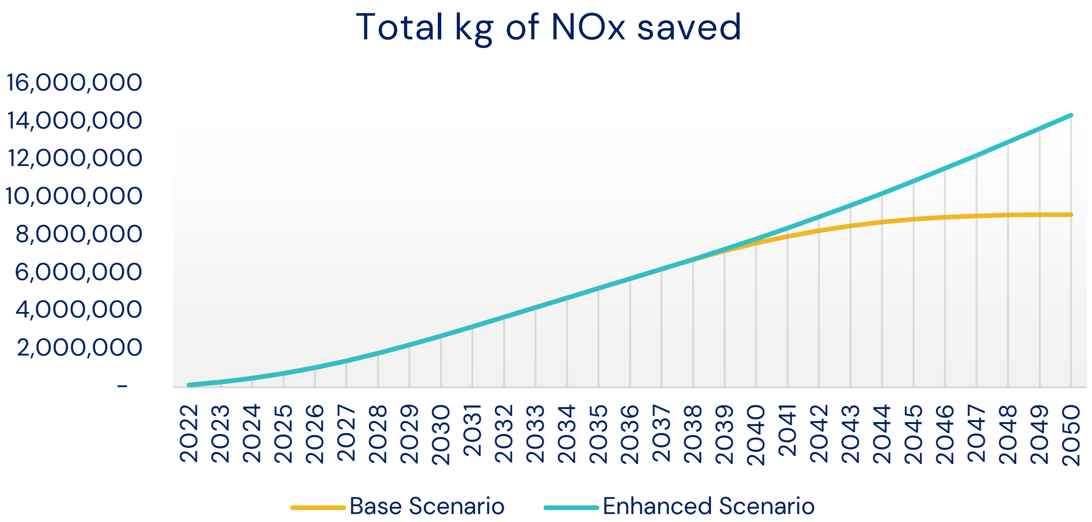
In the base scenario, by shifting to e-buses, the city can reduce emissions to 4.051 $ktCO_2e$ until 2030, provided the envisaged electric buses replace the current conventional bus fleet. If the target for 2038 is met and the city manages to electrify its bus fleet fully, the total emissions saved will be about 18.147 $ktCO_2e$ until 2050.

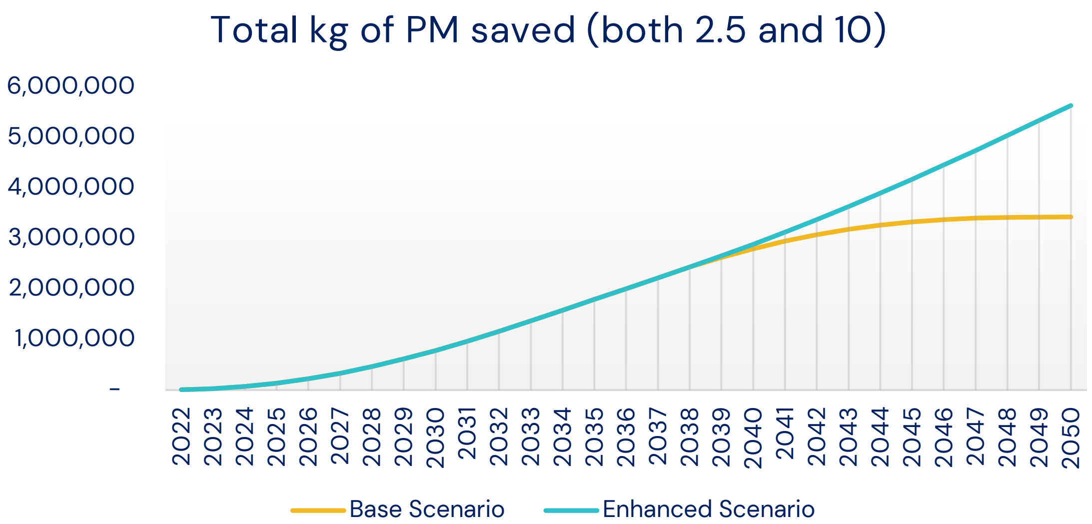
In the enhanced scenario, the city will reduce about 30.000 $ktCO_2e$ up to 2050. As over 80% of the Brazilian energy mix originates from hydropower and other renewable energy sources, the improvement in the grid makes a minor difference in the emissions. The high magnitude of savings in GHG emissions is primarily due to the large number of e-buses replacing conventional buses.



Concerning urban air quality improvement, in the base scenario, the city will reduce about 131 tons of black carbon, 7.736 tons of NOx and 2.901 tons of particulate matter up to 2050. By 2050, São Paulo will save 215 tons of black carbon, 12.320 tons of NOx and 4.833 tons of particulate matter for the enhanced scenario. The savings from the enhanced scenario are almost doubled compared to the base scenario. Thus, improving the current target may potentially reach or even exceed the level of savings that are estimated by the enhanced scenario.







Emission reduction potential at a national level

Through the NDC update in 2022, Brazil targeted 50% emissions below 2005 levels by 2030 and aims to be climate neutral by 2050[8]. In 2020, IEA reported that 182.5 Mt of CO_2 were emitted by the transportation sector in Brazil, of which 92% were emitted from road transportation[9].

On a national level, E-BEAT estimates that the average annual CO_2 savings per bus in Brazil for the enhanced scenario are 60 tonnes and 61 tonnes in 2030 and 2050, respectively. Assuming the steady growth of bus fleet size to population ratio and a 75% shift from ICE buses to e-buses, it is estimated that the annual CO_2 savings will reach 37 Mt in 2030 and

[8] Climate Action Tracker, 'Brazil'.

[9] IEA, 'Greenhouse Gas Emissions from Energy'.

53 Mt in 2050. To put into context, the number is then compared to the 2020 road transport emission level. It shows that by shifting the ICE buses into e-buses, Brazil will reduce 22% and 32% of their road transport emission in 2030 and 2050, respectively.

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