Climate and Air Quality Scenarios for E-Bus Deployment:

Deep Dive City Rio de Janeiro, Brazil

City Characteristics

Rio de Janeiro is the second most populated city in Brazil[1], with an estimated population of 6.7 million people on a territory of 1.204 km^2 making the population density around 5.556 inhabitants per square km^2[2]. The state capital forms, together with 21 other cities, the Metropolitan Region of Rio de Janeiro is inhabited by around 12 million people or 75% of the state's population[3].

RJ has the second largest municipal GDP in the country, U$364.05 billion[4]. The services sector is the most important in the GDP composition, followed by industrial activity and agribusiness.

The RJ area has a high degree of temporal and spatial variation in meteorological elements. Rio de Janeiro has experienced numerous events of heavy and/or prolonged rainfall and has suffered from floods and landslides. Meteorological phenomena involving rainfall records and forecasts, winds, extreme temperatures, ocean surges and other natural variables cause impacts on the city's infrastructure and urban logistics or various risks to citizens. The main climate hazards for Rio de Janeiro include the rise of the average sea level, landslides, floods, and heat waves[5].

Transport system

The public transport bus fleet consists of 6.374 vehicles, of which 291 vehicles are part of the Bus Rapid Transit (BRT) subsystem, operating in exclusive lanes, with low-floor articulated vehicle technology. The subway system has two lines of 48 km and 35 stations that connect the city from end to end. The railway system has five train lines, 258 km long and 108 stations, connecting the city to the municipalities of the metropolitan region. There is also one waterway network that connects the city with its islands (Paquetá and Governador) and with the city of Niterói.

The city experiences daily long kilometres of congestion. However, in recent years, the city's structural transport network has been systematically expanded, benefiting all regions with

[1] Statista, 'Brazil'.
[2] TUMI E-Bus Mission, 'Factsheet - Rio de Janeiro'.
[3] Brookings Global Cities Initiative, 'Rio de Janeiro Metropolitan Area Profile'.
[4] TUMI E-Bus Mission, 'Factsheet - Rio de Janeiro'.
[5] TUMI E-Bus Mission.

significant improvements in urban mobility and a reduction in the population's commuting time.

Public transportation covers ca. 47% of the trips of RJ residents, with buses being used for 37% of all trips, while the second most used mode of transportation is walking, (27% of trips), followed by trips made by car (car mode: 22.74%), and taxis (7%)[6].

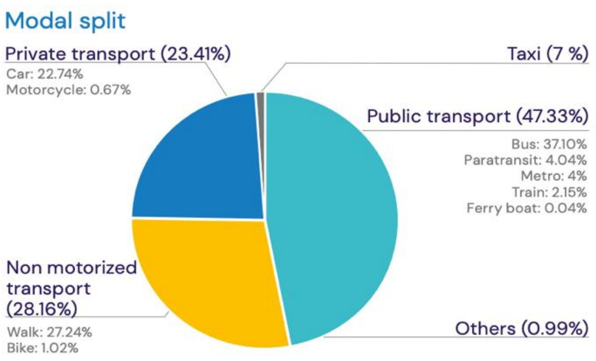


Figure 1: Modal share of Rio de Janeiro. Source: TUMI E-Bus, 2022

The Sustainable Urban Mobility Plan, developed by the RJ City Hall through the Municipal Transportation Secretariat (SMTR), guides public investments in the city's transportation infrastructure for ten years, starting in 2016. The PMUS integrates motorized and non-motorized modes into a cohesive and sustainable system, prioritizing public transport, walking, and cycling, and considering greenhouse gas emissions.

Climate and air pollution targets

The Municipal GHG Emissions Inventory totals 11.3 million tons of carbon equivalent. The transport sector presents the main percentage of emissions (41.25%), followed by the stationary energy (30.24%) and waste (28.51%) sectors. RJ's climate targets comprise a 20% reduction in greenhouse gas emissions by 2030, compared to the 2017 base year - and to reach climate neutrality by 2050. Projects such as the electrification of 100% of the municipal bus fleet by 2050 and implementing a Neutral District in the central region by 2030 are ways to reach that goal[7].

Target	2030	2050
The modal share of walking	30%	32%
The modal share of cycling	4%	8%
Share of non-emitting buses	20%	100%
Share of non-emitting vehicles (entire circulating fleet)	3%	40%

[6] TUMI E-Bus Mission.

[7] TUMI E-Bus Mission, 'Factsheet - Rio de Janeiro'.

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 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	920	0	920	7.970
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. For RJ, this means that 62 e-buses will operate in 2024, and 1300 in 2030. 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 RJ.

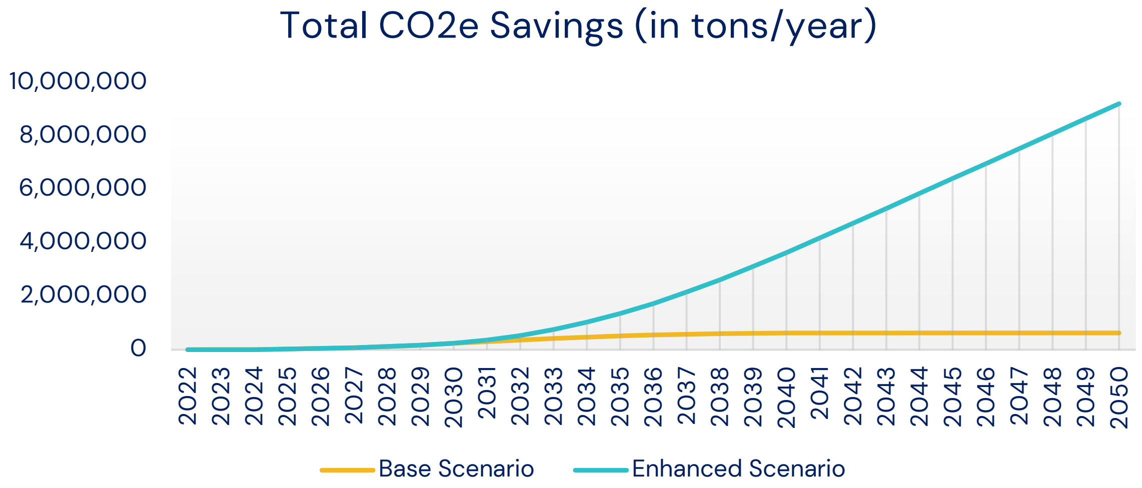
We estimated the fleet up to 2050 based on the population growth in the city. We assumed the fleet availability per 1000 inhabitants would remain unchanged until 2050. This means that 7.970 e-buses would operate in RJ in 2050. Taking into account bus retirements, RJ would need to procure a total of 17,390 e-buses between 2023 and 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:

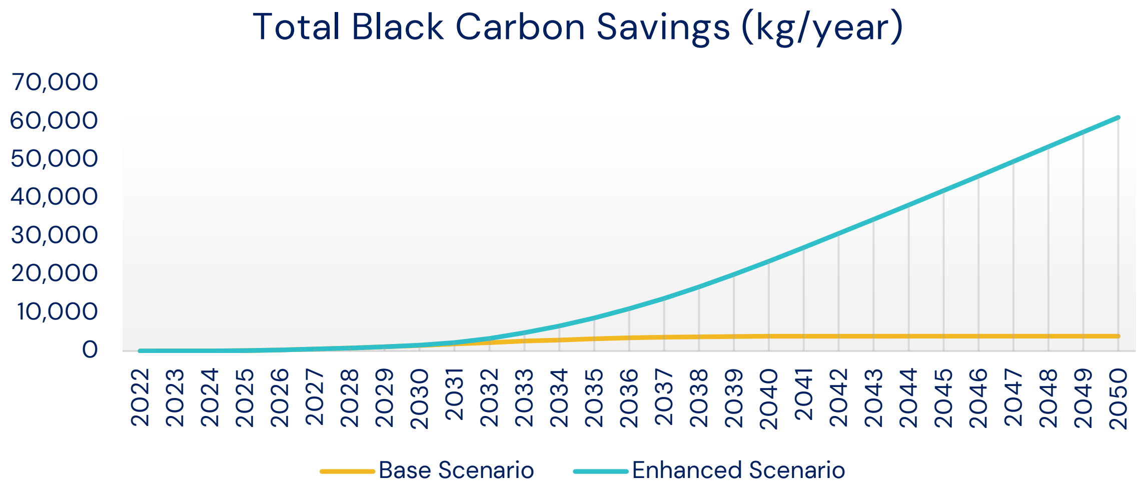
Category (unit)	Base Scenario		Enhanced Scenario	
	Up to 2030	*Up to 2050*	*Up to 2030*	*Up to 2050*
BC (tons)	1	4	1	61
CH_4 (tons)	8	22	8	323
CO (tons)	56	148	56	2.173
CO_2 (kilo tons)	238	627	239	9.195
CO_2e (kilo tons)	239	628	239	9.207
N_2O (tons)	2	4	2	61
NMVOC (tons)	8	21	8	315
NO_x (tons)	87	230	88	3.479
PM_{10} (tons)	25	66	25	985
$PM2_{.5}$ (tons)	13	33	13	495
SO_x (tons)	0	0	0	0
TSP (tons)	38	101	38	1.494
Energy consumption (MWh)	370.000	990.000	380.000	15.990.000
Energy consumption (TOE)	30.000	80.000	30.000	1.370.000

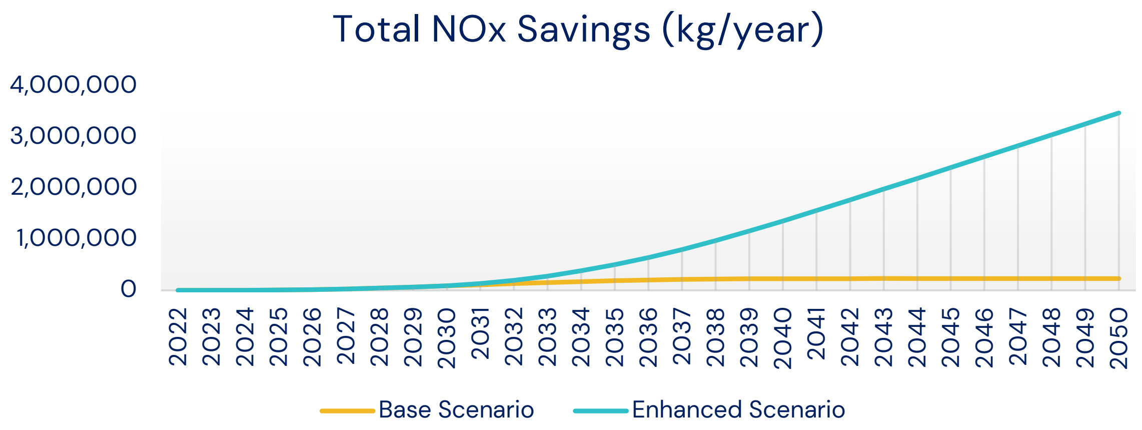
In the base scenario, by shifting to e-buses, the city can reduce emissions by 239 $ktCO_2e$ until 2030, provided the envisaged electric buses replace the current conventional bus fleet. Until 2050, the total emissions saved in the base scenario will be about 628 $ktCO_2e$.

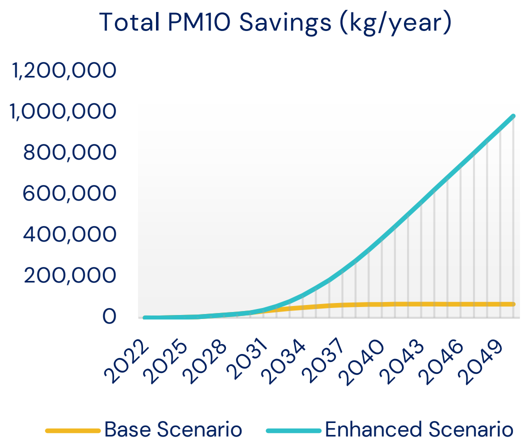
In the enhanced scenario, the city will reduce about 239 $ktCO_2e$ up to 2030 and over 9 million tCO_2e up to 2050. As over 80% of the Brazilian energy mix originates from hydropower and other renewable energy sources, the improvement in the grid makes a minor difference in the emissions. The high magnitude of savings in GHG emissions is primarily due to the large number of e-buses replacing conventional buses.

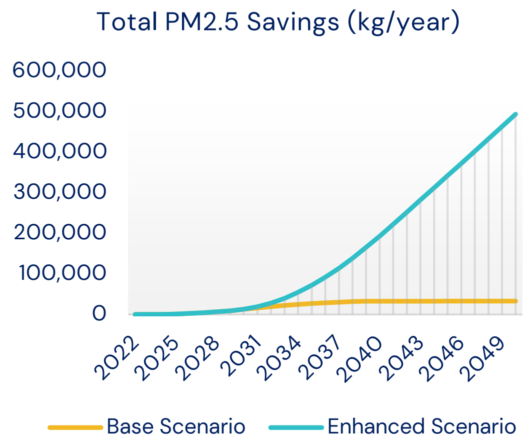


Electric buses decrease greenhouse gas emissions and improve air quality in the local area. The transition towards e-buses is expected to save the city an amount of black carbon, with an estimated 1 ton in 2030 and 4 tons by 2050 in the base scenario. Furthermore, the base scenario also predicts a significant reduction of about 230 tons of NOx and 99 tons of particulate matter saved by 2050. These figures demonstrate the benefits of switching to electric buses to the environment and the local community. In the enhanced scenario, the reductions in black carbon, NOx, and particulate matter by 2050 are 61 tons, 3.479 tons, and 1.480 tons, respectively. The savings of black carbon and NOx from the enhanced scenario are almost fifteen times larger compared to the base scenario and five times larger for the particulate matter. 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 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.

[8] Climate Action Tracker, 'Brazil'.

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

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