Climate and Air Quality Scenarios for E-Bus Deployment:

Deep Dive City Bogotá, Colombia

City Characteristics

Bogotá is Colombia's capital and largest city, located in its own Distrito Capital and divided into 20 localities or districts. The city has a population of 8,1 million in 2018 and covers an area of 1.587 square kilometres. The greater Bogotá metropolitan area, with an estimated population of 11 million, covers 4.321 square kilometres and has a density of approximately 2.500 inhabitants per square km.

Bogotá is situated in the Andean Region, one of Colombia's six regions, and on the Cundiboyacense plateau, on the savanna that bears its name, at an elevation of 2.600 meters above sea level. The average temperature is 11 degrees Celsius, and the city receives around 1.300mm of precipitation yearly. Bogotá has a GDP of 511 billion US dollars, while the national average in Colombia is 6.104.1 US dollars per capita in 2021.

Transport system

Public transport and walking represent the most important means of transportation, with 39% and 32% modal share, respectively. Cars and Taxis have a contribution of 7% and 5%. Motorcycles and cycling represent 5% and 4% of the model split.

Bogotá has four relevant public transport modes: Metró de Bogotá, BRT TransMilenio, Cable car TransMiCable, and Bike Registration System. The metro system is operated by Metro de Bogota S.A, a state-owned company, and consists of Line 1 (red, 17 stations) and Line 2 (yellow, 12 stations)[1]. The Bus Rapid Transit system is operated by TransMilenio, a district entity, serves 1,7 million passengers per day and consists of 1.254 trunk buses and 516 feeder buses, serving 114 stations, 81km are exclusive bus lanes[2]. The TransMiCable cable car, operated by Transdev Colombia, connects "Ciudad Bolivar", a neighbourhood in the south of Bogotá with four stops and serves 22,000 passengers per

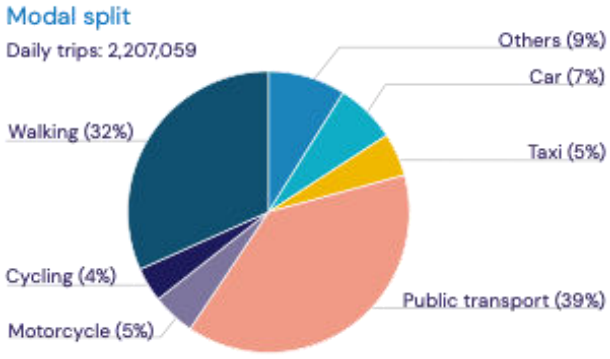


Figure 1: Modal Split. Source: TUMI E-Bus Mission (2022)

[1] Metro de Bogota, 'Sistema Metro'; Government of Bogota, 'Empresa Metro de Bogotá S.A'.

[2] UNECE, 'BRT BOGOTÁ (COLOMBIA): TransMilenio System'; TransMilenio, 'Historia de TransMilenio'.

day[3]. In 2018, a voluntary Bicycle Registration System was introduced to link all bicycles to their owners and aim to reduce thefts and facilitate stolen bikes' return to their owners[4].

Climate and air pollution targets

In 2020, Bogotá declared a climate emergency –the first large city in Latin America to do so. The declaration consists of actions and compliance as follows. Among others, Energy transition and greenhouse gas reduction are listed. The declaration mentioned that "Bogotá shall take urgent action to replace the use of fossil fuels to reduce greenhouse gas emissions by 50% by 2030, with baseline 2020"[5]. Specifically, this goal is supposed to be achieved via zero-emission mobility, public infrastructure and urban planning, renewable energy, emissions targets and monitoring, and financing.

In addition, according to Bogota´s Comprehensive Air Quality Management Plan, the city plans to reduce 10% of particulate matter reduction through almost USD 8 million investment[6].

Targets and policies related to the procurement of e-buses

The national law 1964 / 2019 promoting the use of electric vehicles states that Colombian cities with Mass Transit Systems must implement public policies and actions to ensure that a share of the vehicles used is electric or zero-emission vehicles. The law sets obligations for purchasing new zero-emission vehicles:

Year	Minimum share of zero-emission vehicles in new purchases	Year	Minimum share of zero-emission vehicles in new purchases
2025	10%	**2031**	60%
2027	20%	**2033**	80%
2029	40%	**2050**	100%

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, further 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.

[3] Transdev, 'TransMicable'.
[4] ICLEI, 'Bogota, Colombia: EcoMobility Alliance City'.
[5] C40, 'Bogotá's Climate Emergency Declaration'.
[6] Breathe Life, 'Bogotá Unveils Ambition to Cut Air Pollution by 10% in Four Years'.

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. In addition, 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 accelerated e-bus procurement, we have developed two scenarios: 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	5.450	0	10.440	16.200
T&D Losses	12%	12%	10%	6%
% of Renewable Energy	73%	79%	73%	79%

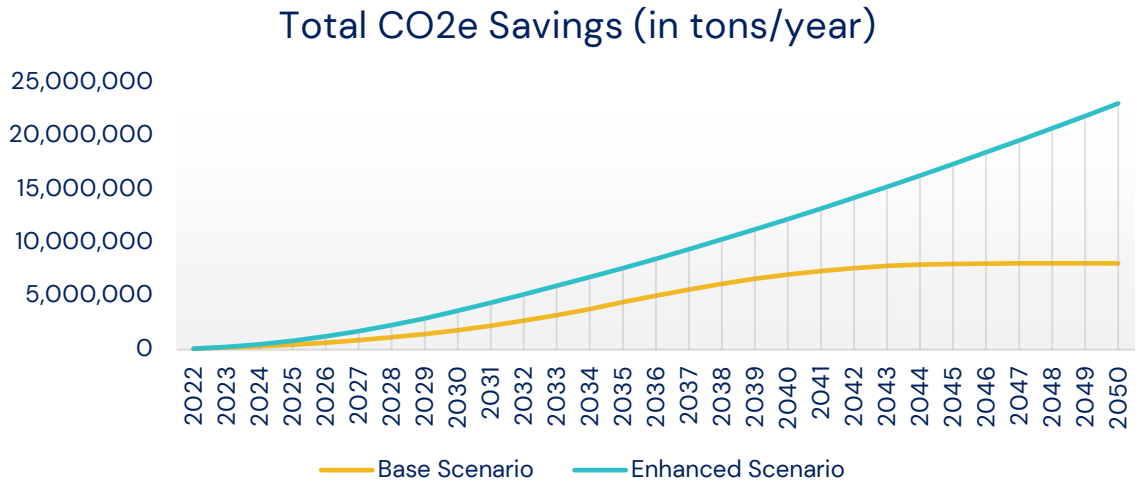
In the **base scenario**, we have considered both short-term and long-term targets set by the city (i.e., 1.485 e-buses by 2022) up to 2050. The data was obtained from the TUMI e-bus network website and updated figures from the TUMI partners. Moreover, we assumed a moderate increase in the share of renewable energy sources in the electricity mix to 79% and constant transmission & distribution losses of 12%.

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. Unless that city had no specific target, 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 an approximate fleet size of 16.200 vehicles in 2050, and the city needs to procure 42.234 e-buses until 2050, considering the vehicle retirement up to 2050. In addition, we assumed that the future electricity mix will have a higher share of renewable energy at 79% and that transmission and distribution losses will gradually be reduced to 6% by 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:

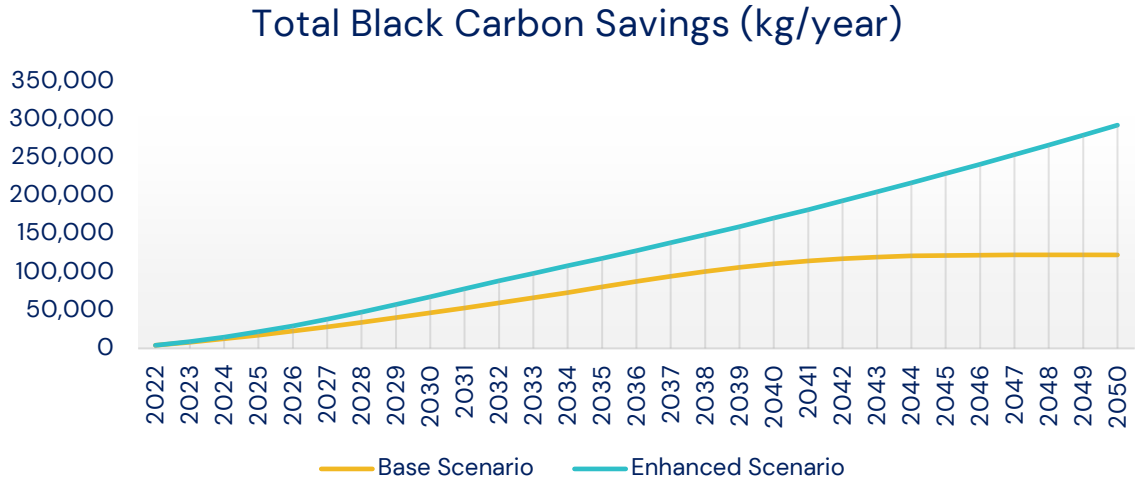
Category (unit)	Base Scenario		Enhanced Scenario	
	Up to 2030	*Up to 2050*	*Up to 2030*	*Up to 2050*
BC (tons)	47	122	68	292
CH_4 (tons)	77	332	152	927
CO (tons)	1.425	3.098	1.866	6.759
CO_2 (kilo tons)	1.823	8.053	3.622	22.994
CO_2e (kilo tons)	1.825	8.064	3.627	23.027
N_2O (tons)	14	61	28	170
NMVOC (tons)	50	160	75	476
NO_x (tons)	5.865	8.755	6.441	14.082
PM_{10} (tons)	195	1.027	440	3.003
$PM2_{.5}$ (tons)	111	551	239	1.597
SO_x (tons)	-15	-57	-30	-140
TSP (tons)	284	1.533	653	4.502
Energy consumption (MWh)	3.630.000	15.990.000	7.230.000	46.850.000
Energy consumption (TOE)	310.000	1.380.000	620.000	4.030.000

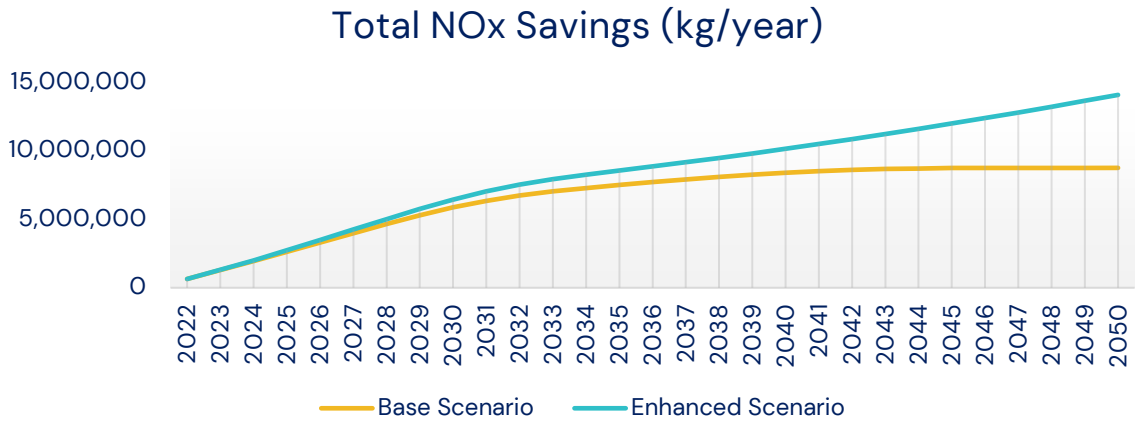
By shifting to e-buses, the base scenario shows a reduction of 1.825 $ktCO_2e$ emissions by 2030. In the long-term, until 2050, the reduction amounts to about 8.064 $ktCO_2e$. The amount of CO_2e reduced for the enhanced scenario by 2030 is around 3.627 $ktCO_2e$, while by 2050 the saving increases almost three times more than the base scenario by 23.027 $ktCO_2e$.

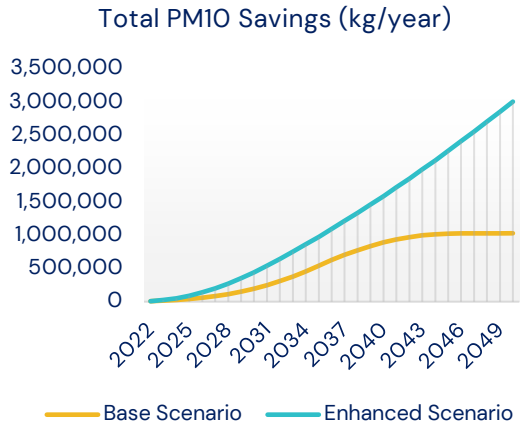


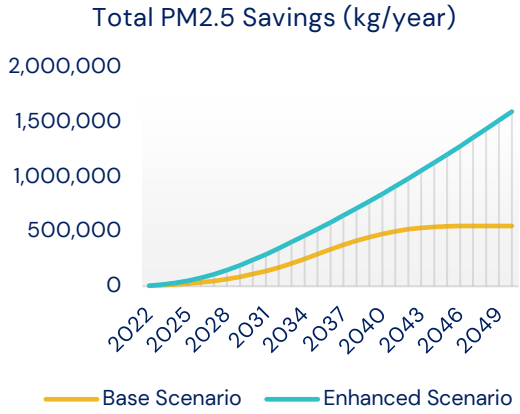
Electric buses decrease greenhouse gas emissions and improve air quality in the local area. The transition towards e-buses is expected to save the city a significant amount of black carbon, with an estimated 47 tons in 2030 and 122 tons by 2050 in the base scenario. Furthermore, the base scenario also predicts a significant reduction of about 8.755 tons of NOx and 1.578 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 292 tons, 14.082 tons and 4.600 tons, respectively. The savings from the enhanced scenario are more than double 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 2020 and 2021, Colombia targeted 51% emissions below 2005 levels by 2030 and aims to be climate neutral by 2050[7]. In 2020, IEA reported that 27 Mt of CO_2 were emitted by the transportation sector in Colombia, of which 98% were emitted from road transportation[8].

On a national level, E-BEAT estimates that the average annual CO_2 savings per bus in Colombia for the enhanced scenario are 49 tonnes and 53 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 9 Mt in 2030 and 12 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, Colombia will reduce 33% and 44% of its road transport emission in 2030 and 2050, respectively.

[7] Climate Action Tracker, 'Colombia'.

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

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