Climate and Air Quality Scenarios for E-Bus Deployment:

Deep Dive City Guadalajara, México

City Characteristics

Guadalajara has a population of approximately 1.5 million (2016), whereas the metropolitan area's population is estimated to be 5 million. The respective area is 151 km^2 and 2,734 km^2 for the metropolitan area, with resulting densities of approximately 9,000 inhabitants per km2 and 1,800 inhabitants per km^2, respectively.

Guadalajara is the capital of the state of Jalisco. The state is in the centre west of Mexico, and the city is situated approximately 550km from Mexico City (DF) and 320km from the coast. Guadalajara's altitude is 1,500m on average. The city comprises four urban districts – Guadalajara, Tlaquepaque, Tonala, and Zapopan – and two suburban ones: Tlajomulco and El Salto.

Guadalajara's climate is mild, ranging from 13 to 35 degrees Celsius throughout the year. The variability from season to season is relatively small. January is the coolest, May is the warmest month. While the winters are dry, the summer months produce most of the annual rainfall of 983 mm/year.

The city has an estimated GDP per capita of USD 18.800, compared to a national average in Mexico of 10,045.7 (current) US Dollars per capita in 2021[1]. The prominent economic sectors in Guadalajara are retail trade, services, and temporary accommodation sectors[2]

Transport system

The three most important means of transportation are walking (37% modal share), public transport (28%), and car (27%). Other motorized mobility is minor, i.e. taxi (3%) and motorcycle (1%). Active cycling contributes only 2%.

The car fleet is approximately 620,000 or 507 cars per 1,000 inhabitants in 2021, which is higher than the Mexican average of 391 cars per 1,000 inhabitants. Public transport modes are Light Rail Transit (LRT), Paratransit, Macrobus and Peribus BRT, Trolleybuses, Electric bus lines, and Bike sharing (MIBICI). 5200 busses carry approximately 377,000 pax/day (based on approximately 68 million pax during the first 6 months of 2021). 55.7% of the public transport passengers are women. In June 2022, the bus fleet comprised 53 electric buses (25 trolleybuses and 38 e-buses).

[1] Metroverse, 'What Is Guadalajara's Economic Composition?'; World Bank, 'World Bank Open Data: Mexico'.
[2] Data Mexico, 'Guadalajara'.

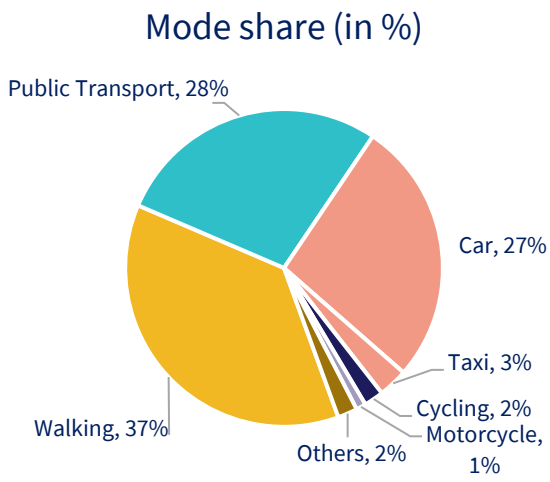


Figure 1: Modal Split. Source: TUMI E-Bus Mission, 2022

In 2022, a 41.5 km BRT corridor "Mi Macro Periférico" along the ring road was opened. The BRT system includes new feeder routes, including a 42.2 km 100% electric bus corridor which is operated by 38 8.6m electric buses[3].

The light train system Sistema de Tren Eléctrico Urbano (SITEUR) consisting of three lines is owned by the state. The Sistema Integral del Tren Ligero (SITREN) represents a bus system, feeding the SITEUR system. The city also has a bus rapid transit system called Guadalajara Macrobús (branded as Mi Macro).

Climate and air pollution targets

In 2020 the Metropolitan Area of Guadalajara launched a Climate Action Plan consisting of three main objectives: 1. A carbon-neutral metropolis based on integrated waste management, mass and non-motorized mobility, efficient energy use and renewable energy supply; 2. An inclusive metropolis that is sustainable and resilient to climate impacts; A coordinated, participatory and inclusive metropolis with climate leadership[4].

Guadalajara is signatory of the C40 'Clean Air Accelerator: How cities are cleaning the air we beath' and pledged to "set ambitious reduction targets for air pollutants" and to "implement new substantive policies and programmes to address the top causes of air pollution emissions", inter alia by transitioning its vehicle fleet from diesel to electric[5].

More specifically, Guadalajara's vision for net zero urban mobility consists of:

(i) becoming carbon neutral by 2050,
(ii) increasing users of SITEUR by 20% by 2030 and increasing the number of cycle paths,
(iii) electrify at least 10.9% of the private car fleet,
(iv) save 885,637 tons of CO_2 by 2030.

[3] C40 Cities Finance Facility, 'Feeder Route for Mi Macro Periférico Guadalajara, Jalisco, Mexico'.
[4] UNFCCC, 'Climate Action Plan of the Metropolitan Area of Guadalajara'.
[5] C40 Cities, 'C40 Clean Air Accelerator, Annual City Progress Report September 2021 - September 2022'.

Targets and policies related to the procurement of e-buses

The electric bus system of Jalisco aims to become the benchmark for electric transportation in the country. Therefore, a range of measures in terms of capacity building is necessary concerning (a) legal structure, (b) project sizing, (c) financing options for the entire project, (d) development of tools for financial monitoring and follow-up, (e) sizing of loading yards, (f) planning and operational design of corridors, and (g) cost structuring and concession model. Implementation started on 4.7.2021.

The e-bus line to Guadalajara airport is in operation and represents the first electric line in the country. The demand began with an estimated 2,000 pax/day but has increased to 5,258 pax/day with up to 8,480 pax/day. But one needs to consider that these figures are affected by restrictions due to the pandemic, and it had not yet been connected to the airport. It is important to monitor the performance review and autonomies further.

The current bus fleet consists of 5147 ICE buses and 63 e-buses. Guadalajara has set the short-term target to have 250 electric buses operating by 2023. This number should quadruple to 1,000 by 2030.

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	1.000	0	1.000	7.600
T&D Losses	18%	18%	15%	9%
% of Renewable Energy	35%	48%	41%	75%

In the **base scenario**, we have considered both short-term and long-term targets set by the city up to 2050 (i.e., 250 e-buses by 2023; and 1,000 e-buses by 2030), while the current fleet size remains constant at 5210 vehicles. The data was obtained from the TUMI e-bus network website and updated figures from the TUMI partners. For Mexico, we have estimated an increase of 48% in the electricity generated from renewable sources and the T&D losses will remain at 18% up to 2050.

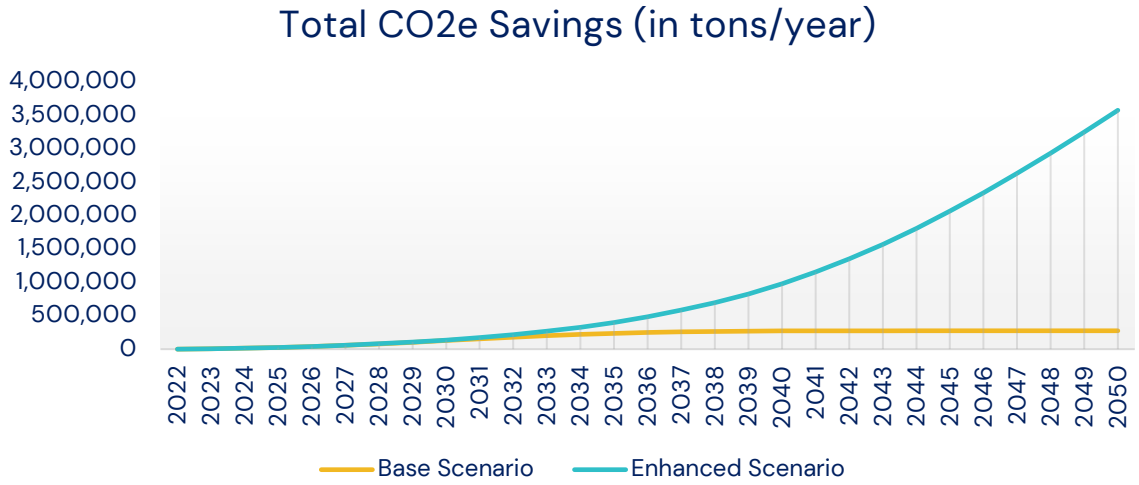
In the **enhanced scenario**, a key assumption was that the entire bus fleet is electrified by 2050. We estimated the fleet up to 2050 based on the population growth in the city. We assumed the fleet availability per 1000 inhabitants would remain unchanged until 2050, leading to a fleet of 7.600 buses in 2050, and the city needs to procure 13.490 e-buses until 2050, considering the vehicle retirement up to 2050. For Mexico, we have assumed that the share of electricity generated from renewable sources will increase to 75%, and the T&D losses will gradually reduce 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)	2	5	2	45
CH_4 (tons)	8	17	9	162
CO (tons)	24	55	26	812
CO_2 (kilo tons)	128	274	135	3.569
CO_2e (kilo tons)	128	275	135	3.575
N_2O (tons)	2	3	2	30
NMVOC (tons)	-15	-26	-14	-38
NO_x (tons)	2	20	8	1.103

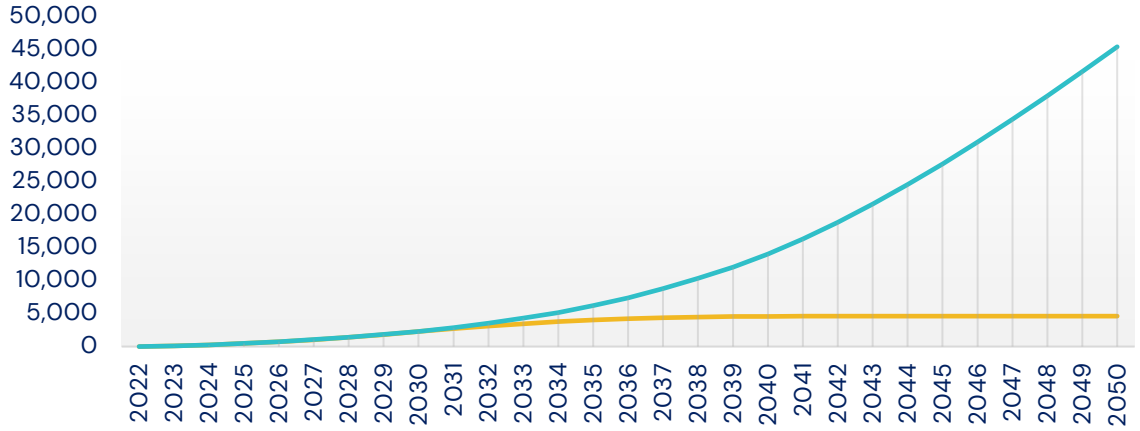
PM_{10} (tons)	24	49	24	503
$PM2.5$ (tons)	11	23	12	253
SO_x (tons)	-4	-9	-4	-44
TSP (tons)	37	75	38	764
Energy consumption (MWh)	380.000	770.000	390.000	8.080.000
Energy consumption (TOE)	30.000	70.000	30.000	690.000

In the base scenario, by shifting to e-buses, the city can reduce emissions to 128 $ktCO_2e$ until 2030, provided the envisaged electric buses replace the current conventional bus fleet. If the targets for full electrification are met, the total CO_2e emissions saved will be about 275 $ktCO_2e$ until 2050. In the enhanced scenario, the city will reduce about 3.575 $ktCO_2e$ up to 2050, or thirteen times the base scenario reduction. Thus, improving the current target may potentially reach or even exceed the level of savings that are estimated by the enhanced scenario.

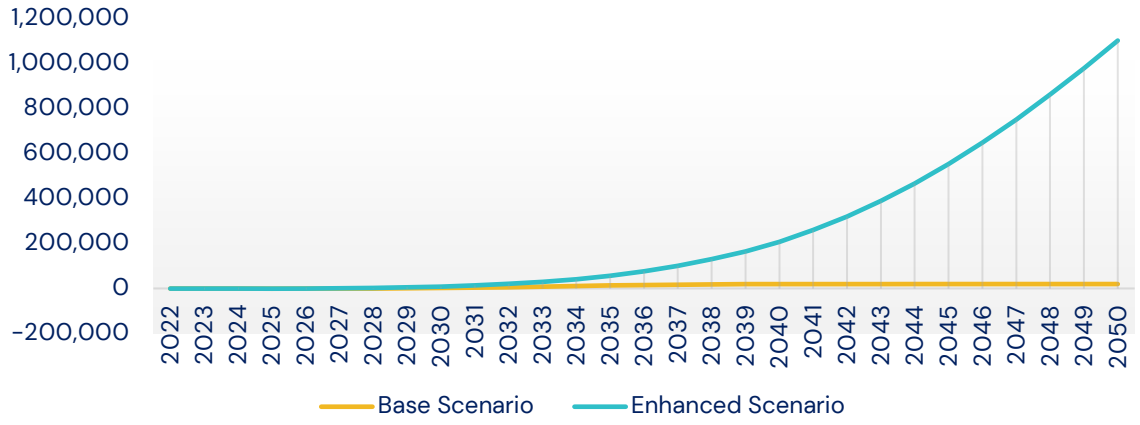


Electric buses decrease greenhouse gas emissions and improve air quality in the local area. The transition towards e-buses is expected to save the city a significant amount of black carbon, with an estimated 2 tons in 2030 and 5 tons by 2050 in the base scenario. Furthermore, the base scenario also predicts a significant reduction of about 20 tons of NOx and 72 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 45 tons, 1.103 tons and 756 tons, respectively. The savings from the enhanced scenario are almost ten to thirty times larger compared to the base scenario.

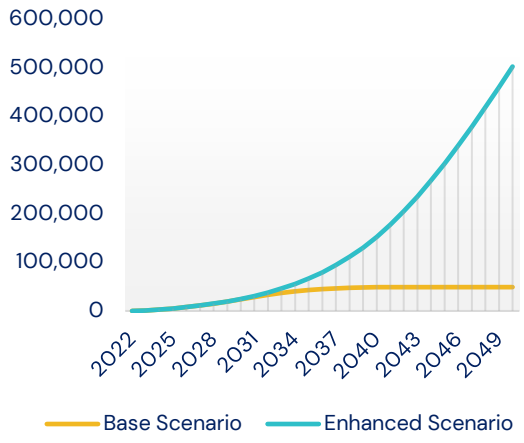
Total Black Carbon Savings (kg/year)



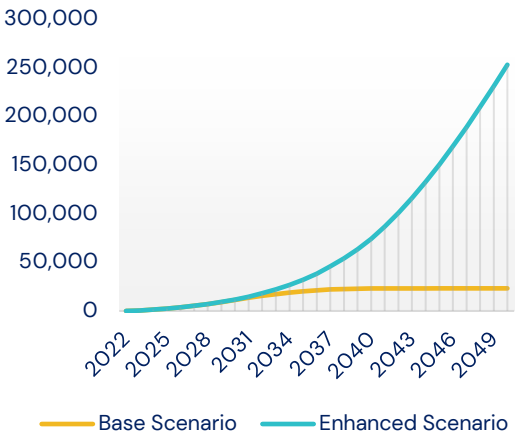
Total NOx Savings (kg/year)



Total PM10 Savings (kg/year)



Total PM2.5 Savings (kg/year)



Emission reduction potential at a national level

In their updated NDC of 2022, Mexico targeted 35% GHG emissions below BAU by 2030[6]. In 2020, IEA reported that 106 Mt of CO_2 were emitted by the transportation sector in Mexico, of which 98% were emitted from road transportation[7].

On a national level, E-BEAT estimates that the average annual CO_2 savings per bus in Mexico for the enhanced scenario are 28 tonnes and 43 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 13 Mt in 2030 and 31 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, Mexico can reduce 12% and 29% of their road transport emission in 2030 and 2050, respectively.

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[6] Climate Action Tracker, 'Mexico'.

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