Climate and Air Quality Scenarios for E-Bus Deployment:

Deep Dive City Bangalore, India

City Characteristics

Bangalore, also called Bengaluru, is the capital of Karnataka state. It is located in the south-eastern region of the state on the Deccan Plateau, at a height of over 900 m above sea level. The city has a population of 13.6 million (2023) in an area of 741 square km. Bangalore is one of the fastest-growing cities in India. With the growth of the IT industry and other manufacturing industries, Bangalore has become a major attraction for people and businesses. Bangalore is the third most populous city and the 5th most populous urban area. The population density of Bangalore has increased by 3.14% in 2023. The city population density is over 4 inhabitants thousand per square kilometre in 2011[1]. The GDP of Bangalore is around US dollar 300 billion[2], with a GDP per capita of roughly USD 25,461 compared to India's GDP per capita of USD 7,242 in 2021[3]. Bangalore has been ranked as the fourth most productive metro area in India.

Bangalore has a tropical savanna climate with wet and dry seasons, with an average temperature of 26°C to 34°C and annual rainfall of 990mm (185 mm highest). The climate-related risk includes extreme events such as heat waves and extreme rainfall leading to floods/droughts. The frequency of the most intense tropical cyclones is also possible in some areas[4].

Transport system

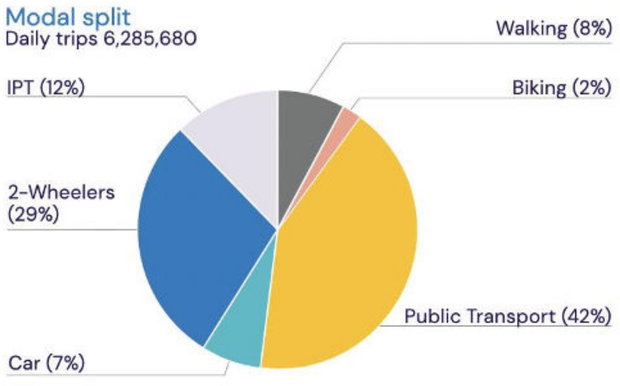


Figure 1: Modal Split. Source: TUMI E-Bus (2022)

Bangalore residents make approximately 6.3 million trips daily. Public transport is the most popular mode of transportation, accounting for 42% of all trips. Meanwhile, 29% of trips are made using 2-wheelers, 12% using IPT, 8% on foot, 7% in private cars, and 2% on bicycles. BMTC is responsible for operating city buses, while Namma Metro runs the Metro Rail system. Additionally, ATCAG, a bike-sharing

[1] World Population Review, 'Bangalore Population 2023'.

[2] C40 Cities, 'Bengaluru'.

[3] World Bank, 'India'.

[4] ADB, 'Climate Change Assessment: Bengaluru Metro Rail Project'.

system, and IPT modes like Autos and taxi aggregators provide last-mile connectivity for public transportation in Bangalore, complementing BMTC and Metro services.

As of June 2022, Bangalore's public transportation fleet consists of 6,812 ICE buses and 90 e-buses, operating on a total of 2,040 bus routes. These routes transport 2.5 to 3.0 million passengers, with each bus travelling an average of 200 km. The fleet has an average age of 7.9 years and a utilization rate of 58.6%. To improve fleet efficiency, BMTC has implemented ITS systems and introduced smart cards for bus integration services.

BMTC was the first Indian state transport undertaking to try e-buses in 2014. They plan to have 300 12-m non-AC e-buses by 2022 and aim to add 1,800 non-AC e-buses by 2024. They received Rs. 50 crore funds to purchase 90 non-AC e-buses. BMTC aims to electrify their entire bus fleet by 2035.

Climate and air pollution targets

Transportation accounts for a significant portion of Bangalore's greenhouse gas emissions and air pollution. Between 1980 and 2016, vehicle registration in the city increased by 10%, contributing to 44% of the city's greenhouse gas emissions[5]. Additionally, transport is responsible for 56% of PM2.5 emissions, with buses accounting for 25% of that total. To address these issues, Bangalore has started developing a Climate Action and Resilience Plan (CAP) through a collaborative effort led by Bruhat Bengaluru Mahanagara Palike (BBMP). This initiative aims to identify mitigative actions that the city can take by conducting a data-driven GHG emission inventory specifically for Bangalore.

Targets and policies related to the procurement of e-buses

"The BMTC has a clear and flexible long-term commitment and strategy for e-mobility, focusing on e-buses, financing mechanisms, and operating models. The Bangalore Comprehensive Mobility Plan aims to provide efficient and sustainable transportation for all through a multimodal transport system that promotes equitable mobility access[6]. The plan also targets an increase in the mode share of public transport, the regeneration of road infrastructure as a public good, and a reduction in emissions from the transport sector. The city of Bangalore plans to operate 13,500 e-buses by 2030, with a target of 2500 e-buses by 2024. This will lead to a reduction of 0.35 MtCO2 in emissions annually, as opposed to polluting (BS4 diesel) buses. Additionally, this can result in a 1.75 µg/m3 reduction in the city's PM2.5 concentration, contributing to the improvement of Bangalore's air quality.

[5] C40 Cities, 'Benefits of Urban Climate Action: Bangalore - Electric Buses'.

[6] Bangalore Metro Lain Corporation and Directorate of Urban Land Transport, 'Comprehensive Mobility Plan for Bengaluru'.

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	2.180	0	7.860	16.970
T&D Losses	20%	20%	17%	10%
% of Renewable Energy	28%	33%	36%	75%

In the **base scenario**, we have considered both short-term and long-term targets set by the city (i.e., 1.145 e-buses by 2024) 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 33% and constant transmission & distribution losses of 20%.

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

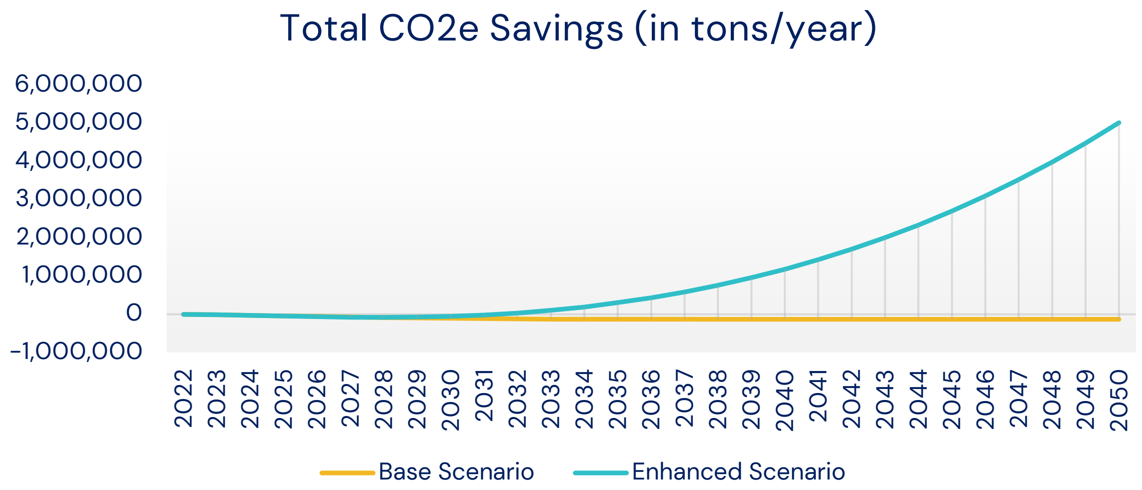
2050. This will lead to an approximate fleet size of 16.970 vehicles in 2050, and the city needs to procure 38.730 e-buses until 2050, considering the vehicle retirement up to 2050. In addition, we assumed that the future electricity mix will have a higher share of renewable energy at 75% and that transmission and distribution losses will gradually be reduced to 10% 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)	7	10	15	136
CH_4 (tons)	23	30	47	405
CO (tons)	155	206	322	2.842
CO_2 (kilo tons)	-107	-132	-58	5.005
CO_2e (kilo tons)	-106	-131	-56	5.018
N_2O (tons)	0	0	1	40
NMVOC (tons)	19	26	41	421
NO_x (tons)	-486	-633	-833	-1.378
PM_{10} (tons)	76	101	159	1.453
$PM2._5$ (tons)	42	56	89	796
SO_x (tons)	-55	-73	-102	-480
TSP (tons)	116	154	243	2.199
Energy consumption (MWh)	1.080.000	1.420.000	2.250.000	19.860.000
Energy consumption (TOE)	90.000	120.000	190.000	1.710.000

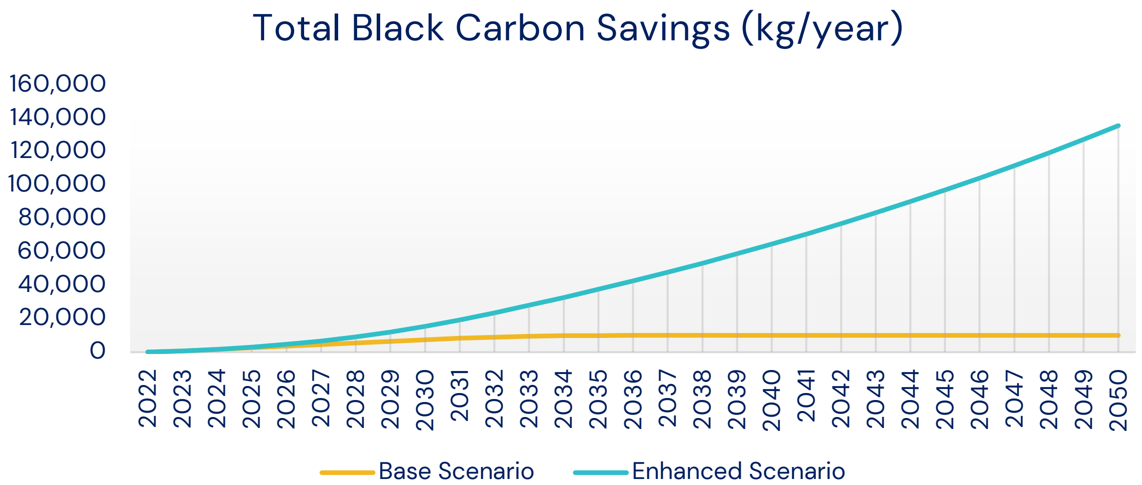
Due to the high dependence on fossil fuels in electricity generation in India, both the base scenario and the enhanced scenario do not provide savings from shifting to e-buses in terms of tCO_2e. As a major share of Indian electricity is sourced from fossil fuels, the de-carbonisation of the energy system, along with improvements in the grid, is required to reduce greenhouse gas emissions from the electrification of (public) transport.

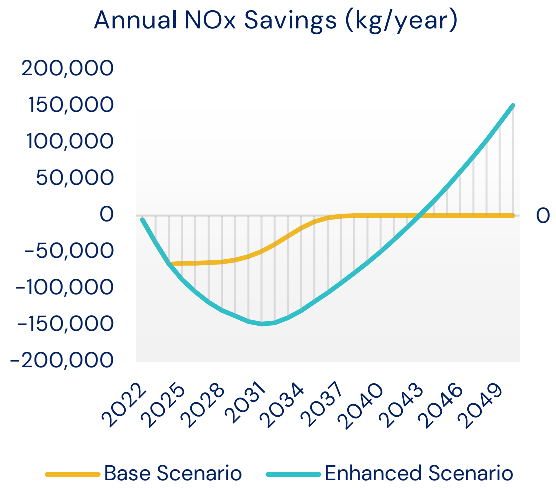
We find that by improving the energy mix and the transmission and distribution losses, the shift to e-buses can give overall GHG savings in 2050, up to 5.018 $ktCO_2e$. Based on the graph, it is evident that there will be a reduction in GHG emissions from 2033 in the enhanced scenario. This scenario involves a shift towards renewable energy sources in the grid mix and an increase in the number of e-buses procured compared to the base scenario.

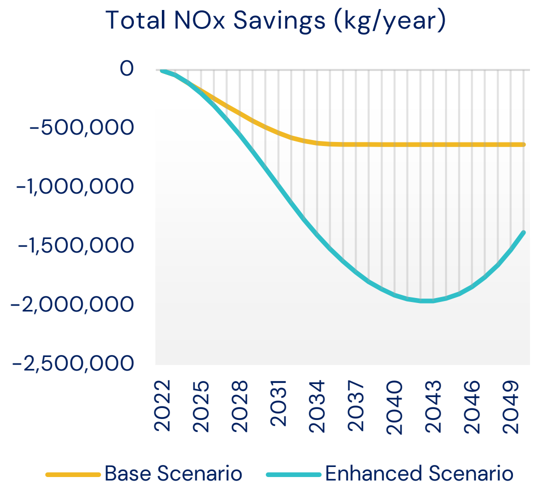


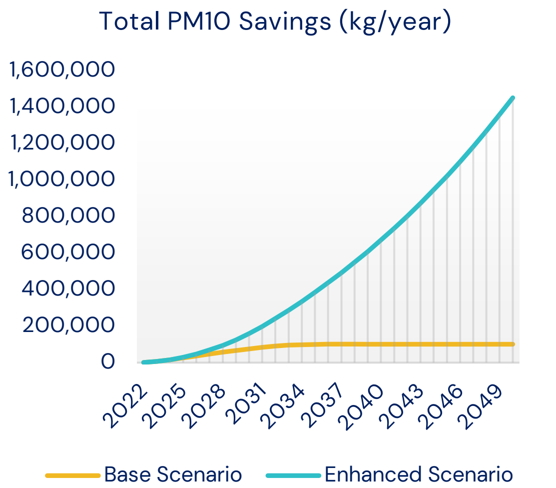
Electric buses decrease greenhouse gas emissions and improve air quality in the local area. The transition towards e-buses is expected to save the city a significant amount of black carbon and particulate matter, with an estimated savings of around 10 tons and 157 tons by 2050 in the base scenario. Furthermore, the enhanced scenario also estimates a significant reduction of 136 tons of black carbon and 2.249 of particulate matter by 2050. The black carbon and particulate matter savings from the enhanced scenario are around thirteen times 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.

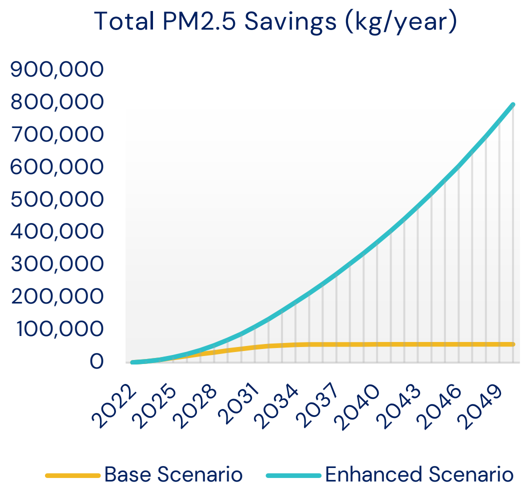
Due to the cumulative reporting of NOx savings, the final cumulative number is negative. Yet, if one sees the annual NOx savings, it can be noticed that in the enhanced scenario cleaning the grid and implementing a large share of e-buses has air quality benefits.











Emission reduction potential at a national level

According to the updated NDC in 2022, India targeted 45% emissions below 2005 levels by 2030 and aims to be climate neutral by 2070[7]. In 2020, IEA reported that 269 Mt of CO_2 were emitted by the transportation sector in India, of which 94% were emitted from road transportation[8].

On a national level, E-BEAT estimates that the average annual CO_2 savings per bus in India for the enhanced scenario are 3 tonnes and 32 tonnes in 2030 and 2050, respectively. The striking difference between 2030 and 2050 savings is mainly due to India's high dependence on coal for its electricity generation. Currently, coal represents 70% of the country's energy mix, despite the country's plan to reduce it to 50% by 2030[9]. Meanwhile,

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[7] Climate Action Tracker, 'India'.
[8] IEA, 'Greenhouse Gas Emissions from Energy'.
[9] Climate Action Tracker, 'India'.

E-BEAT enhanced scenario assumes that 75% of the grid generation will be sourced from renewables.

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 7 Mt in 2030 and 168 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, India will reduce 3% and 67% of their road transport emission in 2030 and 2050, respectively. Furthermore, the savings percentage can potentially increase to 89% in 2050 by shifting 100% of buses from ICE buses to e-buses.

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