Climate and Air Quality Scenarios for E-Bus Deployment:

Deep Dive City Delhi, India

City Characteristics

Delhi is a union territory in northern India and the country's capital. It is the only city State in India with an urban population of 97.5 per cent. As per Census 2011, it had a population of 16.8 million which had risen to 20.5 million by 2021[1]. Spread over an area of 1,484 km^2 with a density of over 13,400 persons per km^2, Delhi is India's second largest urban agglomeration after Mumbai[2].

The Delhi government is also called the Government of National Capital Territory of Delhi (GNCTD), which is trifurcated into three Municipal corporations – Delhi Municipal Corporation (DMC), New Delhi Municipal Corporation (NDMC) and Delhi Cantonment Board (DCB) for the better management of urban services. The Delhi metropolitan region, also known as Delhi National Capital Region (NCR), is spread over 55,083 km^2 and has an overall population of over 46 million[3].

Delhi has an average elevation of 217m, and its topography is mostly flat, with a few hills in the northern part of the city. The Yamuna River, which is the largest river in the region, flows through the city from west to east.

The climate in Delhi is semi-arid, with hot summers, average rainfall and moderate winters. The maximum mean monthly temperature ranges from 9.1°C in January to 40.1°C in May. The city has an average annual temperature of 24°C and an annual average precipitation of 617mm[4]. Heavy monsoon rainfall in the catchment area of the Yamuna results in a dangerous flood situation for the city. In contrast, dust storms are frequent during the summer months leading to an immense build-up of particulate matter in the atmosphere. Other risks include fire outbreaks, air pollution, and high risks of earthquakes[5].

Delhi experiences vibrant trade and commerce and offers employment opportunities, which results in massive immigration. The city had a nominal GDP per capita of ca. US$ 4,600. In comparison, the national average nominal GDP for India is US$ 2301.42 per capita in 2021[6].

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[1] TUMI E-Bus Mission, 'Factsheet - Delhi'.
[2] Department of Environment, Government of NCT of Delhi, 'Delhi State Action Plan on Climate Change'.
[3] National Capital Region Planning Board, 'Regional Plan 2021'.
[4] Department of Environment, Government of NCT of Delhi, 'Delhi State Action Plan on Climate Change'.
[5] TUMI E-Bus Mission, 'Factsheet - Delhi'.
[6] World Bank, 'India'.

Transport system

NCTD has the highest number of registered vehicles (ca. 10 million) in India. In addition, approximately 1.1 million vehicles enter or leave the region daily[7]. As a result, Delhi has ca. 21% of its land area under roads. Residents of Delhi make an average of 1.2 trips per day[8], and ca. 3.2 million people commute in and across the city, using public transport daily.

The transport system mostly relies on various forms of public transport (ca. 31% modal split), such as city buses and metro trains, followed by active forms of transport like walking and biking, which collectively account for 39% of the modal split. Furthermore, private motorised vehicles like cars, taxis and two-wheelers take up to 23% of the modal split, leaving 7% for intermediate public transport options such as autorickshaws and cycle rickshaws[9].

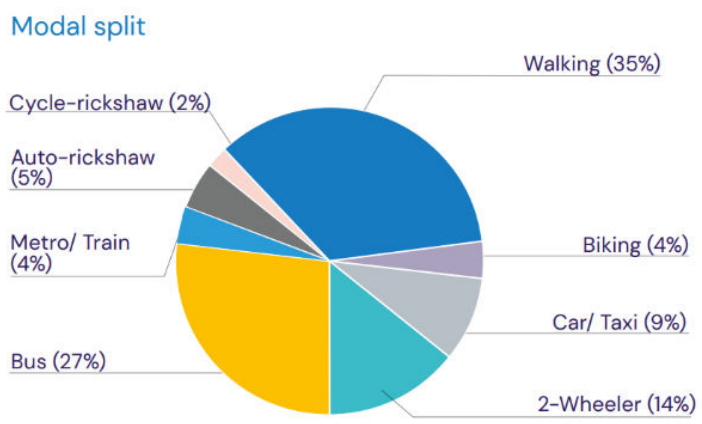

Figure 1: Modal Split. Source: (TUMI E-Bus Mission 2022)

The public transport system of Delhi consists of a well-developed transport network based on ring and radial patterns and a suburban rail system, including the Mass Rapid Transit System (MRTS). The MRTS consists of eight lines and ca. 1 million passengers used metro trains daily in 2021[10].

More than 2 million passengers ride buses in Delhi per day[11]. Buses operate on 502 routes and cater to about 60% of the total transportation demand[12]. The state-owned Delhi Transport Corporation (DTC) is a major bus service provider and operates the world's largest fleet of CNG-fuelled buses and has a ridership of 1.5 million passengers daily[13]. It has an existing infrastructure of 40 depots, and a fleet size of 3944 buses, comprising 1,275 A.C. low-floor buses, 2,506 Non-A.C. low-floor buses, 163 Standard buses[14] and 3319 cluster buses[15]. On the other hand, Delhi Integrated Multi-Modal Transit System Ltd. (DIMTS), a joint venture

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[7] Gupta and Dameniya, 'Rapid Assessment of Trael Patterns in Delhi - Horizon Year 2030 & 2050'.
[8] Gupta and Dameniya.
[9] TUMI E-Bus Mission, 'Factsheet - Delhi'.
[10] 'Avg. Daily Ridership of Delhi Metro at 10 Lakh, down from 57 Lakh Pre-Lockdown'.
[11] TUMI E-Bus Mission, 'Factsheet - Delhi'.
[12] Department of Environment, Government of NCT of Delhi, 'Delhi State Action Plan on Climate Change'.
[13] TUMI E-Bus Mission, 'Factsheet - Delhi'.
[14] Department of Environment, Government of NCT of Delhi, 'Delhi State Action Plan on Climate Change'.
[15] '100 E-Buses to Join Delhi Transport Corporation Fleet in 2 Weeks'.

between the Delhi state government and the non-profit IDFC foundation, operates 1725 buses in the city[16] with a ridership of 0.9 million passengers daily[17].

Climate and air pollution targets

The Delhi government published its first Action Plan on Climate Change (DSAPCC) for 2010-2020 in 2018. The DSAPCC focused on six areas, with goals to decarbonize its energy, transport and agricultural sectors. Inter alia, the city of Delhi aims to increase the modal share of public transport and intermediate public transport options from 53% to 73% by 2030[18].

Targets and policies related to the procurement of e-buses

The Delhi Electric Vehicle Policy 2020 targets to ensure that 25% of all new vehicles and 50% of all new buses are electric by 2024. The vision is to bring down transport emissions by ensuring early success in electrifying city bus services and establishing a durable foundation for faster e-mobility adoption[19].

By the end of 2022, Delhi's bus fleet consisted of 7139 ICE buses (CNG)[20]. GNCTD procured 300 e-buses by the end of 2022 under the Gross Cost Contract (GCC) model and applied for another 1,500 e-buses under the e-bus Grand Challenge for cities conducted by Convergence Energy Services Limited (CESL). In addition to these 1800 e-buses, GNCTD is committed to procuring ca. 6380 more e-buses under the Grand Challenge Phase-II which is scheduled to be conducted by CESL in 2023[21].

Out of these 6380 e-buses, DTC and DIMTS will collectively procure 4,100 12m e-buses, 2080 9m e-buses and 200 double-decker e-buses. With this, the e-buses share in Delhi's fleet is expected to increase from 2 per cent in 2022 to 70 per cent in 2025[22].

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[16] Bhatia, 'DIMTS'.

[17] TUMI E-Bus Mission, 'Factsheet - Delhi'.

[18] Department of Environment, Government of NCT of Delhi, 'Delhi State Action Plan on Climate Change'.

[19] TUMI E-Bus Mission, 'Factsheet - Delhi'.

[20] Dialogue and Development Commission of Delhi, Department of Transport, Government of NCT of Delhi, and RMI India Foundation, 'Accelerating Electric Mobility in Delhi: Journey and Insights from Implementing the Delhi Electric Vehicles Policy. August 2022'.

[21] Dialogue and Development Commission of Delhi, Department of Transport, Government of NCT of Delhi, and RMI India Foundation.

[22] Dialogue and Development Commission of Delhi, Department of Transport, Government of NCT of Delhi, and RMI India Foundation.

Table 1: Targets for electric bus adaptation (Source: Dialogue and Development Commission of Delhi, Department of Transport, Government of NCT of Delhi, and RMI India Foundation 2022)

Targets for electric bus adaptation in Delhi	
2022	2% electrification (Procurement of 300, 12m low floor AC e-buses) and electrification of 3 bus depots
2023	10% electrification (Procurement of 1500, 12m low floor AC and 100 9.5m AC e-buses) and electrification of 26 bus depots
2025	70% electrification (Procurement of 6380 e-buses)

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	9.500	0	9.500	18.890
T&D Losses	20%	20%	17%	10%
% of Renewable Energy	28%	33%	36%	75%

In the **base scenario**, we have considered procurement targets set by the city (i.e. 1,800 e-buses by 2023). 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%.

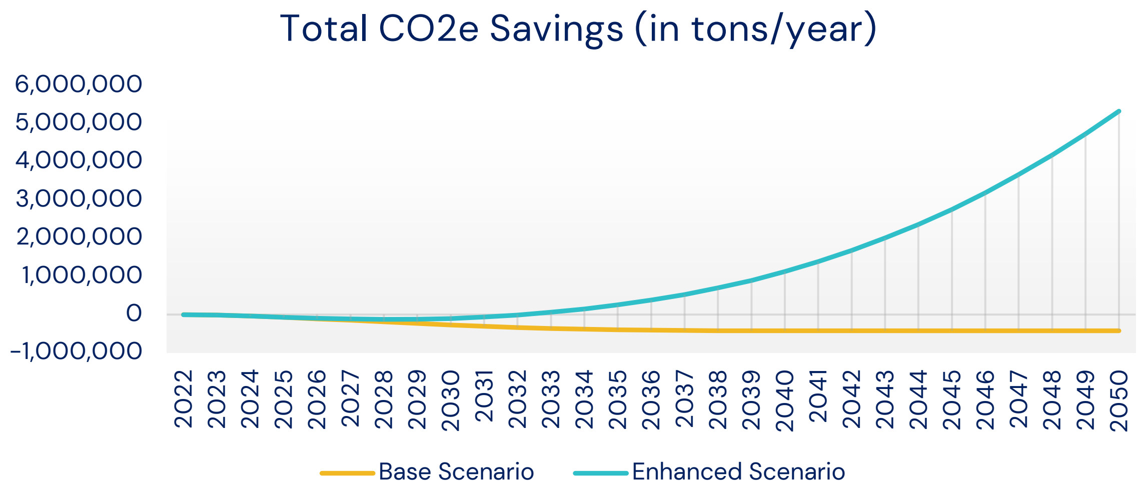
In the **enhanced scenario**, a key assumption was that the entire bus fleet is electrified by 2050 unless the city defined an earlier target for full electrification. We estimated the fleet up to 2050 based on the population growth in the city. We assumed the fleet availability per 1000 inhabitants would remain unchanged until 2050. This leads to a fleet size of 18.890 vehicles in 2050, and the city needs to procure 42.890 e-buses until 2050, considering the vehicle retirement up to 2050. In addition, we assumed that the future electricity mix has a higher share of renewable energy 75% and that transmission and distribution losses will gradually be halved 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)	21	41	21	150
CH_4 (tons)	63	121	64	445
CO (tons)	429	832	437	3.123
CO_2 (kilo tons)	-273	-428	-104	5.314
CO_2e (kilo tons)	-271	-425	-102	5.329
N_2O (tons)	0	1	1	43
NMVOC (tons)	53	105	56	461
NO_x (tons)	-1.313	-2.420	-1.154	-1.680
PM_{10} (tons)	211	409	217	1.603
$PM2_{.5}$ (tons)	118	229	121	879
SO_x (tons)	-151	-284	-141	-541
TSP (tons)	323	625	332	2.427
Energy consumption (MWh)	2.970.000	5.740.000	3.030.000	21.700.000
Energy consumption (TOE)	260.000	490.000	260.000	1.870.000

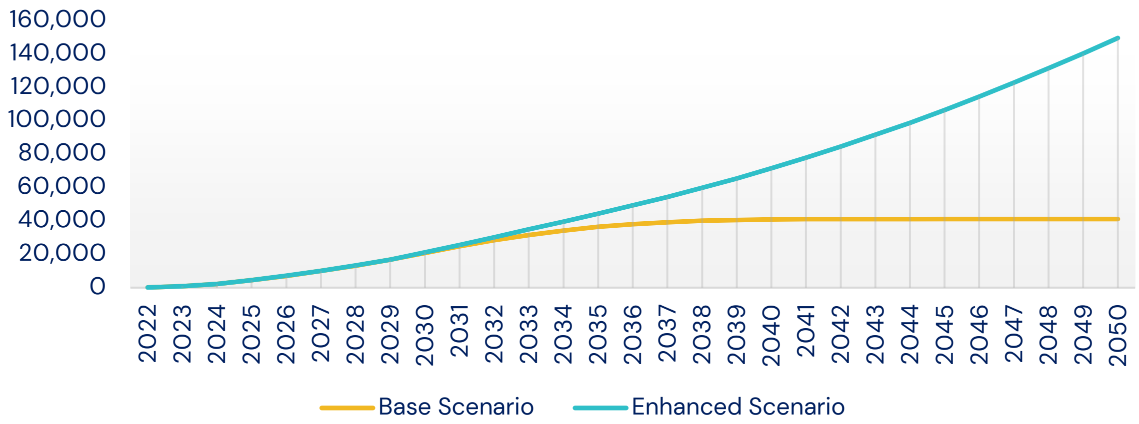
In the base scenario, shifting to e-buses increases the emissions of CO_2e, both in 2030 and in the long term until 2050. This is due to the high carbon intensity of the Indian electricity mix, and the increased fleet size. Only if the enhanced scenario for 2050 is realised, and less carbon-intensive electricity is available, the electrification of Delhi's bus fleet will contribute to reduced CO_2e emissions.

In the enhanced scenario, the city will reduce about 5.329 ktCO_2e up to 2050. 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.



In terms of air quality, savings are seen in reducing black carbon and particulate matter. By 2030, both the base and enhanced scenarios show black carbon reduction by 21 tons. By 2050, the base scenario shows a 41 tons reduction of black carbon, while the reduction for the enhanced scenario is at 150 tons. In addition, particulate matter reduction by 2050 for the base scenario and enhanced scenario is at 638 tons and 2.482 tons, respectively. 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.

Total Black Carbon Savings (kg/year)



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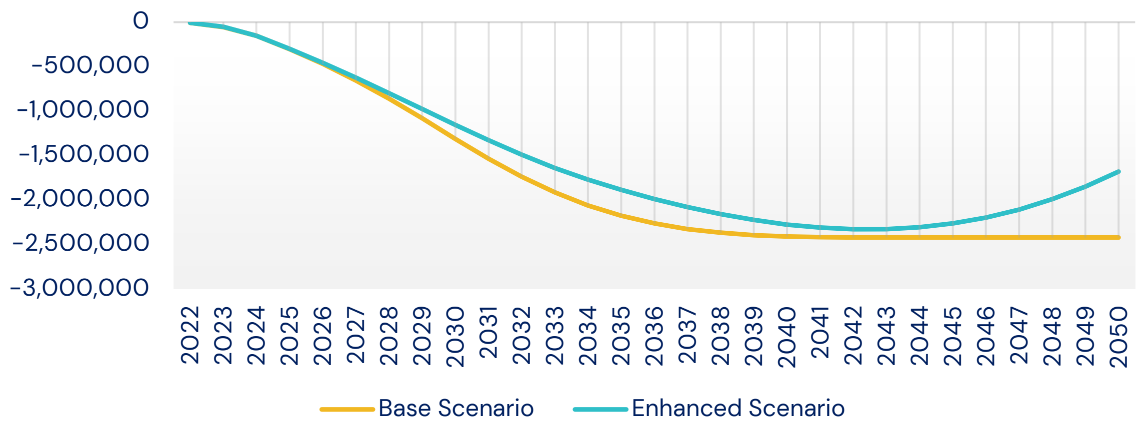
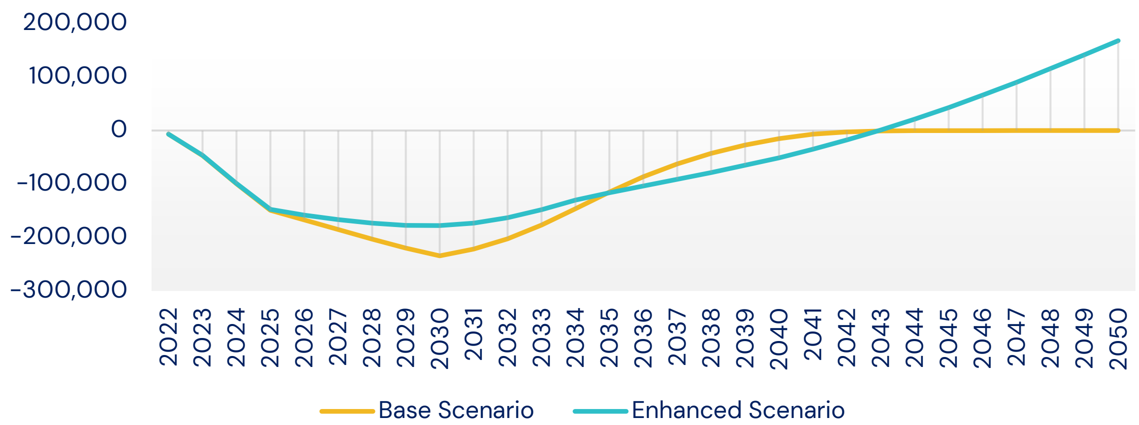
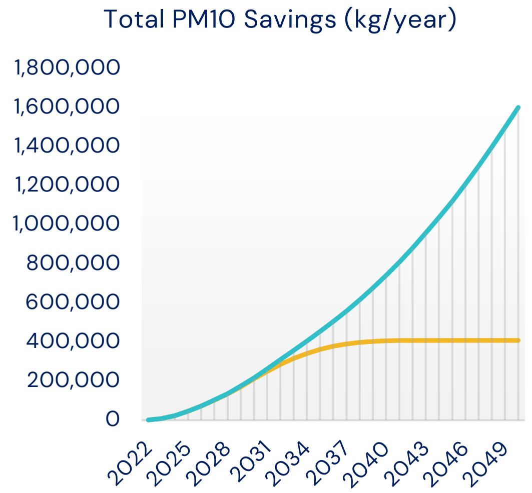
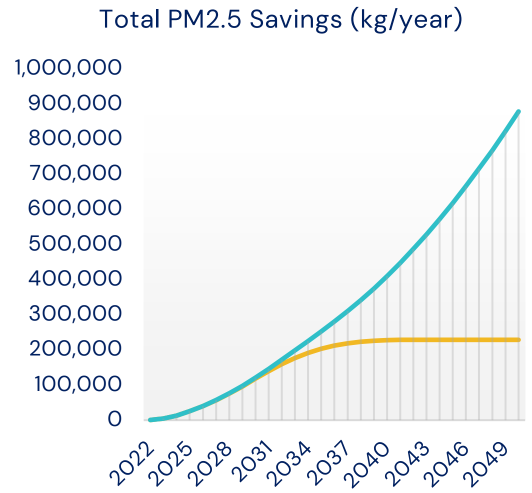


Annual NOx Savings (kg/year)







Emission reduction potential at a national level

According to the NDC update in 2022, India targeted 45% emissions below 2005 levels by 2030 and aims to be climate neutral by 2070[23]. 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[24].

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[25]. Meanwhile, 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.

[23] Climate Action Tracker, 'India'.
[24] IEA, 'Greenhouse Gas Emissions from Energy'.
[25] Climate Action Tracker, 'India'.

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